VOL. 253 JULY 1955 No. 7

American Journal of Science

Established in 1818 by Benjamin Silliman

EDITORS
JOHN RODGERS—JOSEPH T. GREGORY

ASSOCIATE EDITORS

REGINALD A. DALY, CAMBRIDGE, MASS.
A. F. BUDDINGTON, PRINCETON, N. J.
C. R. LONGWELL
CARL O. DUNBAR
RICHARD F. FLINT
HENRY MARGENAU
HAROLD G. CASSIDY
HORACE WINCHELL
G. EVELYN HUTCHINSON
NEW HAVEN, CONN.
LEASON H. ADAMS
WILMOT H. BRADLEY
WASHINGTON, D. C.
WILLIAM H. TWENHOFEL, ORLANDO, FLORIDA
HOWEL WILLIAMS, BERKELEY, CALIF.
FREDERICK J. ALCOCK, OTTAWA, CANADA
CECIL E. TILLEY, CAMBRIDGE, ENGLAND
GEORGE GAYLORD SIMPSON, NEW YORK, N. Y.
ADOLPH KNOPF, STANFORD, CALIF.

STERLING TOWER
YALE UNIVERSITY
NEW HAVEN, CONNECTICUT

Published monthly. Ten dollars a year. One dollar a copy.
Foreign, ten dollars sixty cents. Canada, ten dollars thirty-five cents.

AMERICAN JOURNAL OF SCIENCE

Established in 1818 by Benjamin Silliman

THE FIRST SCIENTIFIC JOURNAL IN THE UNITED STATES

DEVOTED TO THE GEOLOGICAL SCIENCES AND TO RELATED FIELDS

Editors: JOHN RODGERS—JOSEPH T. GREGORY

Managing Editor: ELIZABETH G. WEINMAN

Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879. Published monthly at Sterling Tower, Yale University, New Haven, Conn.

Subscription rate $10 per year ($1.00 a number). Student rate $5 per year (application blanks available on request). Postage prepaid to the United States; 35 cents per year to Canada; 60 cents per year elsewhere.

The JOURNAL completed its *first* series of 50 volumes in 1845, its *second* series of 50 volumes in 1870, its *third* series of 50 volumes in 1895, its *fourth* series of 50 volumes in 1920, its *fifth* series of 36 volumes in 1938. Since 1938 the numbering by series has been discontinued, and volumes are annual and bear the whole numbers as of 1818, that for 1939 being volume 237.

Back numbers and volumes, also cumulative indices of all series, may with few exceptions be obtained from the office of the AMERICAN JOURNAL OF SCIENCE, Sterling Tower, New Haven, Conn. Positive microfilm copies of each complete volume may be purchased by subscribers to the paper edition from *University Microfilms*, 313 N. First St., Ann Arbor, Michigan. Regular subscribers may purchase each past year in microcard form, from *The Microcard Foundation*, Wesleyan University, Middletown, Connecticut.

INSTRUCTIONS TO CONTRIBUTORS

Manuscripts of articles submitted should follow the recommendations in the pamphlet "Suggestions to Authors" (Lane, 1935) and should be preceded by brief abstracts. They should be checked with special care before being submitted, to avoid changes in proof other than printer's errors.

References to literature should be listed alphabetically by authors at the end of the article; all references should be complete. For articles in journals or other serial publications, the reference should give in order: Author's name, year of publication, full title: name of periodical or series, volume number, inclusive pages. For books or other unnumbered publications, it should give: Author's name, year of publication, full title: place of publication, publisher. This form follows the recommendations in the pamphlet "Abbreviations used in publications of the U. S. Geological Survey", which is also the standard used for abbreviating names of periodicals, etc. Citations within an article should be to author and year, with specific pages wherever appropriate.

Plates (photographs), *figures* (line drawings), and *footnotes* should each be numbered consecutively through each article, using arabic numerals. If two photographs form one plate, they are figures 1 and 2 of that plate.

Illustrations should be neat and legible and should include explanations of symbols used. Copy that cannot be reproduced cannot be accepted. Plates and figures should be capable of reduction to not more than 4 by 7 inches, all lettering being at least 1/16th inch high after reduction. When necessary, one large map or table can be accepted, if it will not exceed 7 inches in width after reduction. Line drawings should be in black India ink on white drawing board, tracing cloth, or coordinate paper printed in blue. Photographs should be positive glossy prints. Photostatic and typewritten material cannot be accepted as copy for illustrations.

Reprints. Thirty separate copies of each article will be furnished to the author free of cost and without previous notice from him; these will be without a cover. Additional copies will be furnished at cost, which will of course be greater if the article is accompanied by plates involving unusual expense. Copies will be furnished with a printed cover giving the title, author, volume, page, and year, when specially ordered.

REFERENCE

Lane, B. H., 1935, Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C. 35c.)

[American Journal of Science, Vol. 253, July 1955, Pp. 377-390]

American Journal of Science
JULY 1955

GEOMORPHIC DEVELOPMENT IN HUMID AND ARID REGIONS: A SYNTHESIS

CHAUNCEY D. HOLMES

ABSTRACT. Arid-climate landscapes are best explained in terms of Penckian geomorphic concepts and have never been satisfactorily integrated with the Davis system of land-form exposition, although integration seems to be quite possible and certainly desirable. Attention should be directed to those landscape elements common to both arid and humid climates.

The fundamental elements in subaerial landscape evolution are the so-called wash slopes and gravity (or derivation) slopes. These are best displayed in arid regions. In humid regions the grass and forest cover have the effect of breaking up these elements into small units, though their essential functions and relationships remain unchanged. Varying ratios of these small wash- and gravity-slope units give the observed range of hillside slopes characteristic of humid regions, tending toward gradual reduction of overall slope angle. In arid regions these two types of slope remain more nearly unbroken and are therefore more conspicuous. When applied broadly through the climatic range, these two fundamental types are regarded as constituting end members of a continuous series. This point of view provides a unified basis for description and interpretation of all landscapes developed by fluvial erosion.

INTRODUCTION

Geomorphic development in arid regions has always had an anomalous status in the Davis scheme of geomorphic interpretation. In establishing his geographical cycle (as it was called in the early years) Davis drew extensively upon the early works of Powell, Dutton, and Gilbert in western and southwestern United States for most of the basic principles of the cycle concept. Yet in those same arid regions, the contrasts with humid-climate landscapes have so impressed most later workers that a separate scheme of interpretation has seemed necessary. Even Davis himself believed in this necessity, and he is perhaps largely responsible for setting the American pattern of thought and viewpoint on topographic development under arid climatic conditions (Davis, 1905). Maintenance of the separate category in popular geology thus established may have offered better professional opportunity than would have been the case had more effort been directed toward harmonizing the two schemes, inasmuch as the humid-cycle principles then appeared to have been thoroughly exploited. At any rate, American geomorphology has continued to carry the dual scheme of "normal" and "arid" cycles without apparent embarassment.

No strong opposition to the Davis doctrines developed in America while the great author was living. The case for pedimentation instead of "normal" peneplanation in the Southwest was satisfactorily established through the work of Bryan (1922) and others, and earlier workers among whom McGee (1897) deserves special mention. But all this was accepted within the Davisian arid cycle without serious misgivings. Opposition from abroad in the form of Penckian doctrines has not been taken seriously by most American geologists

until recently. Formal statement of the Penck system (Penck, 1924) came while Davis was still active, and his writings seemed to refute satisfactorily the tenets of the new school. Consequently the realization that the principles of pedimentation are in essence those of the Penckian system has come as a surprise to many. Now that an authoritative translation of Penck's chief work is available (by Czech and Boswell), its virtues and defects should become more generally appreciated.

The Association of American Geographers sponsored a symposium on Penckian geomorphology in 1939, at which time some of the currently used English equivalent terms were introduced. However, the belated attention of American geologists was drawn more effectively to these geomorphic problems by the publication of von Engeln's *Geomorphology* (1942). Von Engeln had arranged the symposium, and therefore to his efforts we owe a large measure of the present awareness of the Penckian principles among American geologists. But conservatism is strong, and one may detect a perhaps unconscious partisanship in the common tendency to criticize the obvious errors in some Penckian principles or to dwell on their less essential aspects.

Meanwhile other developments have been in process. A recent well-prepared textbook (Gilluly, Waters, and Woodford, 1951) scarcely mentions the time-honored regional young-mature-old Davisian topography, and the omission seems to have created very little comment. This can be taken as evidence of serious and growing suspicion that a goodly part of traditional Davisian teaching is obsolete. Still more specifically, King (1953) has completely rejected both the principle of downwasting of divides and the peneplain as the penultimate land form, in favor of scarp retreat and pediment extension leading to a compound pediment or pediplain. Even Davis himself (1930, p. 136) seems virtually to have acknowledged the existence of pediments in humid climates (he called them valley-floor basements), with the offhand suggestion that he had taken them for granted since about 1908.

Because the primary aim of the Penck system was directed toward interpreting regional diastrophic history, some of the geomorphic principles therein expounded must be disengaged from the tectonics in order to evaluate their significance. Whether the change from convex to concave slopes, in so far as this change can be demonstrated, reflects chiefly rate of uplift may be questioned on the ground that other factors also partially control the angle of slope. For strictly geomorphic interpretation, the diastrophism involved here is as incidental as is the Davisian assumption of rapid uplift followed by stillstand. Likewise the problems of *Knickpunkte* and piedmont benchlands lie only partly in their alleged modes of origin. Of equal or greater importance is the history of these forms once they have come into existence. This is a part of the great central problem of the evolution of valley-side slopes.

ACKNOWLEDGMENT

The writer is indebted to Professor Richard Foster Flint for helpful criticism and suggestions regarding preparation of the manuscript.

THE PROBLEM AND THE APPROACH

To harmonize the concepts of "humid" and "arid" cycles (and incidentally to combine the best elements of the Davis and Penck interpretations),

one must go beyond the obvious field facts that parallel slope retreat prevails in the more arid regions and that gradual reduction in slope angle is equally the rule in the more humid regions. As a first approach, two commonly held alternative propositions may be stated: Either (1) the tendency to parallel slope retreat is inherent in the hydraulic processes and is present under any climatic conditions (Penck); or (2) such tendency arises because of some nonhydraulic factors peculiar to arid climates and absent in humid climates (implied in Davisian theory). A third proposition, namely, that fundamental hydraulic principles depend on the vagaries of climate, is manifestly absurd; yet a hint of this uncritical view is inherent in any insistence that erosion goes on differently in arid and humid regions.

Two related problems seem to hold the possibilities of finding a unifying solution. The first is to recognize in the two climatic domains the fundamental erosion processes and their homologous effects. The second is to account for the differences in terms of controls on the erosion processes.

Most earlier attempts (Davis, 1930; Wood, 1942) to harmonize the phenomena of erosion forms in the two contrasting environments have begun with those of humid climate and proceeded to the arid-climate forms. In reality, the simplest expressions of water-erosion effects are those in arid climates. Therefore on the principle that clarity is best achieved by proceeding from the simpler to the more complex, the following analysis begins with a consideration of arid-type landscapes, followed by those under semi-arid conditions, and then to the humid-climate landscapes. King (1953) has followed this approach in part, but his generalizations have led to revolutionary, rather than evolutionary, conclusions. Nevertheless, all attempts to solve this problem should receive sympathetic consideration.

ADVANCE SUMMARY

This preliminary summary of evidence and deductions is offered in order that the subsequent discussion may be followed more readily.

Slopes are best classified into two fundamental types, in accord with Penck geomorphic interpretation: (1) *wash slopes* (graded surfaces of sediment transport), and (2) *gravity* or *derivation slopes* (surfaces which supply the sediment). In arid regions these two types occur in large-scale units dominating the landscape as pediments of various dimensions, and prominent scarps and mountainsides. Ideally, the wash-slope gradients are controlled only by the local requirements of sediment transportation on them.

In humid regions vegetation impedes both erosion and rate of runoff, resulting in significant contrasts with arid-climate landscapes. (1) Equilibrium wash slopes are under the *dual control* of vegetation and sediment transport over them, and in consequence are steeper than corresponding vegetation-free slopes; whereas valley sides (the chief gravity slopes) are generally less steep. (2) The more complete drainage network creates a correspondingly greater total length of valley sides, and therefore a more varied and intricate areal pattern in which slope retreat may go on. (3) From the beginning of an erosion cycle, rills and sheet runoff slowly lower the upland surface and round off the upper edges of valley walls, creating the character-

istic convex portion of the transverse profile. (4) The strong but partial and inconstant control by vegetation gives rise to slopes of various intermediate degrees of steepness. In detail, these slopes consist of minute gravity-slope units alternating with correspondingly small segments of wash slopes. Local and temporary failure of vegetation on wash slopes permits gullying, the gully sides being new gravity slopes, with new and lower-gradient wash slopes eventually developing.

A notable intermingling of small wash- and gravity-slope units occurs in the zone of rounding at the tops of the valley sides. In effect, the upper part of the valley side removed in the rounding is distributed as inconspicuous minor units through the zone of rounding. The degree of steepness of the rounded slope as casually observed at any one place is an expression of the ratio between the two types of small units. Toward the upland divides, wash-slope units become longer and more numerous, and the uplands themselves may or may not be quite devoid of small gravity-slope units. Toward the valley, gravity-slope units prevail increasingly, and the steepest part of the wall may be uninterrupted gravity slope though modified by vegetation. Similarly, at the foot of the steep valley side a few short wash-slope units appear and become increasingly numerous and continuous as the valley floor is approached. This lower, concave portion of the transverse profile is often erroneously ascribed chiefly to alluvial-fan building. While it is true that considerable amounts of alluvium commonly accumulate at these sites, the surface is nevertheless essentially a wash slope.

All gravity (derivation) slopes of whatever unit-size tend to retreat at their characteristic angle of declivity as determined by local conditions. As these conditions change, so may the angle of declivity inasmuch as it develops originally under the control of existing conditions. The tendency to parallel retreat is believed to be everywhere present, but in humid areas it is masked or modified by the effects of more frequent (though less intense) runoff, by vegetation, and by more complete chemical weathering than is characteristic under arid conditions.

The foregoing analysis leads to the conclusion that the fundamental differences between fluvially developed landscapes in humid and arid climates are chiefly those of proportion and arrangement of the basic slope elements; and that, with appropriate adaptation of terminology, the Davisian framework of topographic interpretation may be applied to any landscape thus developed.

The following discussion makes no mention of soil creep and related processes, but such are assumed to go on as is generally understood.

TWO FUNDAMENTAL PROCESSES AND THEIR DOMAINS

It seems scarcely necessary to state that, following weathering of the surface rocks, landscape development by sediment removal involves two distinct and fundamental processes: erosion (or sediment derivation), and transportation. Yet inasmuch as these two processes result in the mystery of parallel slope retreat under some conditions and gradual slope reduction under others, their natures and their particular domains must be carefully noted.

Geomorphically the most significant effect of transportation by running water is the development of a graded slope, whether it be a stream bed or a sediment-mantled rain-washed surface (Mackin, 1948; Fenneman, 1908; Bryan, 1922; Holmes, 1952). So long as an abundance of sediment in various grade sizes within the competence of the current is available, a stable transportation profile will be established leading down to a local baselevel of one kind or another, and changing gradually in response to changes in sediment supply and volume of water from upslope, or to any shifting of the controlling baselevel.

The domain of sediment derivation lies chiefly in the area above the graded transportation surface. In this domain stream beds are being constantly lowered, and slopes leading to the streams are being stripped of whatever sedimentary particles are within the dislodging power of rills and sheet runoff. In both these domains various controls, notably vegetation and rock resistance to weathering and abrasion, introduce endless variation in overall slope declivities.

These two domains have their clearest expression in arid climates where vegetation controls are at a minimum or lacking altogether, and are ideally represented by the pediment and its limiting mountainside or scarp. For purposes of discussion, it seems best to use tentatively the terminology offered by Meyerhoff (1940). The scarp face or mountainside is the *gravity slope* (Penck's *Steilwand* or *Böschung*), which may also be considered as the *derivation slope*. The graded transportation surface is the *wash slope*, equivalent to Penck's *Abflachungshang* or *Fusshang* (Penck, 1953, p. 418-419).[1] The *Haldenhang* or sub-talus rock slope apparently marks the upper limit of steepness of the wash slope because it evidently indicates approximately the angle of rest of the weathered fragments resting upon it.

As a graded transportation surface, the wash slope has much in common with a braided stream channel. Particles at the edge of a rill or minor channel are moved forward into the rill, shallowing it and allowing it to widen correspondingly. Efficiency of the rill channel is thereby decreased, and the widening causes the rill to subdivide. So long as the amount of available sediment exceeds that which the rills can move simultaneously on any and all parts of the slope, no channel cutting or gullying can take place (Lawson, 1932). In Fenneman's words (1908, p. 746), the potential channel-cutting power of the runoff "is *prevented* rather than *withstood*." The entire surface may be slowly lowered or aggraded, but without losing its graded condition. Davis (1938) has described conditions of incipient channeling of a wash slope during a severe rainstorm, but the abundance of available sediment kept the runoff spread in a manner which well illustrates this principle.

WASH SLOPES UNDER SEMI-ARID CONDITIONS

In its simplest development the wash slope should be completely free from vegetational influence, and controlled only by the abundance of granular sediment. In arid regions, sagebrush and other similar types obstruct runoff to some extent, but vegetational control becomes significant where the

[1] Meyerhoff regarded *Haldenhang* as the wash-slope equivalent.

rainfall is sufficient to sustain a grass cover. As observed on the ground surface, the cover may appear thin and incomplete, but the roots form a continuous mat underneath. The stems, whether standing or fallen, impede and spread the flow of rills, and under these conditions the runoff is presumed to carry its maximum load of sediment. The result is an even-surfaced slope that appears essentially no different from that of typical pediments in the more arid regions. At their upper borders they begin against a scarp or hillside from which comes the bulk of sediment transported across them. An essential characteristic is that of dual control—sediment transportation and vegetational resistance. These controls have operated jointly on these slopes from their beginning, and therefore the gradients represent an equilibrium adjustment at the limit of available transportation energy.

The degree of control inherent in the process of sediment transportation is constant, but that of the grass cover is variable and dependent upon the completeness of that cover. If, when, and where the grass cover is broken, gullying can begin. Then the sides of the gully become small gravity slopes, and the gully widens by slope retreat as well as by stream erosion along its base. But the gully floor, being lower and more moist than the adjacent slopes, acquires a stronger vegetation growth that tends to trap much of the sediment, and such gullies may therefore gradually fill or heal. If they do not heal, the entire slope eventually becomes lowered, with consequently lessened gradient on which the need for vegetational control in maintaining equilibrium is correspondingly reduced. Slopes that illustrate these principles are numerous in the area of Fort Union rocks in southern Montana, in Wyoming, and in many other places. However, in many of these same areas most of the slopes are now being dissected and re-established at lower elevations apparently in response to the present, lowered local baselevel.

Around the northern borders of the Laramie Range, Wyoming, are wash slopes that truncate both the Precambrian granite and the overlying Oligocene-Miocene strata without any topographic expression at the unconformity.[2] Their gradient is slightly higher than that of typical Arizona pediments, but they obviously have developed as equilibrium transportation surfaces. Frye and Smith (1942) have described "pediment-like" surfaces in western Kansas, and more recently Frye (1954) has described similar surfaces in the same region as pediments. All are widening by scarp (valley-side) recession and are in all respects typical wash slopes. Whether the term pediment should be reserved for those wash slopes controlled primarily by the water-spreading power of abundant granular sediment is not discussed here. The alternative term would seem to be valley-floor basements (Davis, 1930, p. 136).

In summary thus far, wash slopes are most conspicuous in arid regions but are equally characteristic of semi-arid to sub-humid regions where impeding vegetation absorbs some of the potential hydraulic energy. The remaining problem is therefore to recognize the corresponding slopes in areas of humid climate. First, however, some features of the gravity slope should be noted.

[2] Blackstone, D. L., personal communication.

THE GRAVITY SLOPE

Although the term gravity slope suggests a surface on which gravity is the chief, or sole, agent in moving loosened fragments to its base, its Penckian equivalent seems to have been applied to landscape elements, at least in the alleged piedmont benchlands, which are far from precipitous. Therefore the term seems applicable to any sediment-yielding surface whose slope is steeper than that of the bordering transport-equilibrium surface with which it merges at its lower edge. Transportation slopes in equilibrium under dual control (vegetation and sediment transport) remain in the category of wash slopes only so long as vegetation continues to be effective. Vegetation failure causes such surfaces to revert to the gravity-type category, though generally the reversion is gradual, spreading with the recession of minor scarps that descend to a new surface of lower gradient. A universal feature of the gravity slope is that the transporting energy of water flowing over it is in excess of that which is taken up in moving the available sediment. Any sediment left stranded on such a surface, following an interval of precipitation runoff, does not form part of a depositional equilibrium surface such as is characteristic of the wash slope.

Distinction between gravity and wash slopes rests therefore on a relative and functional basis rather than on an absolute degree of steepness or gradient; though no wash slopes can be steeper than the sub-talus rock slope (Haldenhang), and only wash slopes may occur at or below the gradient locally controlled by abundance of available sediment, free from vegetational influence. Between these limits, ranging in general from approximately 6° to 30°, both gravity and wash slopes may occur (fig. 1.) In other words, gravity slopes are generally steeper than 6° and wash slopes are never steeper than about 30°. The basis for these distinctions seems clear, necessary, and fundamental; though the possible low angle of the gravity slope makes that term seem inappropriate. *Derivation* slope often seems preferable because it is free from any connotation as to steepness. Gravity slope would then be a special case of the broader category of derivation slopes. At any rate, after the higher gravity slopes have been destroyed, the gradual lowering of wash slopes without loss of graded status involves sediment derivation below the earlier limits of the gravity or derivation surface, but within the limits of equilibrium variation during any one episode of precipitation runoff.

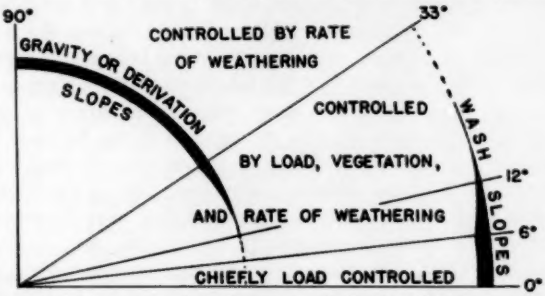


Fig. 1. Diagrammatic interpretation of range in declivities of derivation and wash slopes.

SCARPS AS GRAVITY SLOPES

Except in arid mountain areas where steep slopes extend upward to the ridge summits typical gravity slopes are of moderate height and rise to the resistant edge of a higher surface (wash slope). Most authorities are agreed that such a plains-region scarp cannot retain a sharp or abrupt crest without some kind of resistant capping stratum (Rich, 1938). The degree of resistance required is only relative (and may be inconspicuous), depending on the amount of sheet runoff or rill discharge passing over the brink, and on the rate at which the scarp face beneath it yields to weathering and erosion. The Big Badlands along the White River in South Dakota afford excellent illustrations. Some of the White River strata there are slightly more resistant than others, but the chief brink-forming element is the tough prairie sod. Naturally it cannot withstand the attack of streams flowing from the upland, but it evidently does withstand considerable rill wash. Moreover, it becomes re-established at successively lower elevations and caps many small tabular surfaces at intermediate levels along the general descent to the valley floor. The steepness of scarps beneath these sod brinks is a measure of their control relative to the rate at which the cliff faces recede beneath them. Summits without sod cover either are sharp ridges or are rounded. Obviously a sod cover is far less resistant than most caprocks that come to notice, but the illustrations afforded by the Badlands introduce some important clues regarding scarp retreat.

HUMID-CLIMATE DIVERSIFICATION

The simplest gravity or derivation slope is the ideal straight or linear scarp, which is probably most nearly realized in arid regions. With increasing runoff and humidity of climate, such a scarp would become notched along its weaker segments, with the result that the length of scarp surface is increased. With more surface thus exposed, a more voluminous supply of sediment is weathered and removed from it; and its removal is conditioned by the increased precipitation and runoff. Some of the notches extend ever farther and become enlarged to the dimensions of valleys. This is especially the case with any streams that rise in the hinterland and flow over the scarp face. In effect, therefore, with increasing humidity of climate, the gravity slope is extended along the valley walls throughout the ramifications of the branching and developing drainage system and is best developed in rock at least moderately resistant to weathering. Slopes steeper than about 30° are entirely of the gravity type; and if all valley sides and the slopes around the valley heads were of this degree of steepness, the domain of gravity slopes in humid areas would be easier to discern. Typically, however, the tops of the valley walls lack a sufficiently resistant caprock. They lose their scarp-like appearance by rounding and merge imperceptibly with the lesser gradients toward the divide crests. The basic reason for such rounding is clear. Vegetational resistance to erosion may be approximately uniform over the entire upland; but outward from the divide summit, each unit distance adds its increment of runoff. Therefore the erosive effectiveness of runoff is correspondingly augmented, with the result that increasing steepness of valley-side slopes, out-

ward from the summit, is inevitable. In large part, this convex zone of predominantly wash slope corresponds to any wash slope lying above (and leading down to) a gravity slope, such as the upland above the White River Badlands.

Loss of scarp-like brink at the top of a young valley wall does not mean that the portion of the scarp or gravity slope thus affected is lost. Rather,it is *distributed* as minor scarps over the lower part of the convex area, each minor scarp being a small-scale gravity-slope unit. At the divide, rainwash creates a graded transportation slope, but within a short distance the rills descend individually over miniature scarps (gravity slopes) controlled by tufts of grass, resistant aggregates, fragments too large to move, or some other comparable temporary and very local baselevel. Then may follow more short distances of graded (wash) slopes, and so on. With increasing distance from the divide, the intervals of wash slope become shorter and fewer and the miniature gravity slopes become correspondingly more numerous until the steepest part of the valley side has been reached. Here erosion is at its maximum, and if any straight element of slope occurs anywhere, it is immediately below this line. Lawson (1932) has interpreted such straight segments as indicating removal of sediment as fast as it is loosened by weathering. Also Wood (1942) has called it the constant slope; but it is the most conspicuous and uninterrupted part of the gravity or derivation slope.

Below the limit of uninterrupted gravity slope is the area directly under local baselevel control of the stream channel in the valley. The transition begins with the appearance of small graded rill segments, which become dominant as the rills reach the gentler gradient that completes the concavity of the lower part of the valley wall. Ideally this slope is graded to the top of the stream bank, but with some secondary slopes leading to the stream surface; and if the stream were to follow a permanent course along the valley axis, this ideal might be generally attained. However, with meander shifting and continued valley deepening, the actual elevation of effective baselevel control varies from time to time and from place to place along the valley. Where the stream, having impinged against the valley side, shifts away from that site, the margin of the valley floor there must be aggraded. Immediately upslope, gullying has meanwhile been in progress because of the proximity of the main stream as it cut laterally against the base of the valley side. Then as the fans extend across the new valley floor, the upslope gullies may be filled at least in part in response to the requirements of the longer (restored) graded slope. The amplitude of these fluctuations is commonly beyond the limits of immediate adjustment by the slow process of rill- and rain-wash transportation. This tends to obscure the development of the graded bedrock surface (valley-floor basement of Davis) rising to the base of the retreating valley wall. However, the broad uniformity of these slopes reveals a close approximation to the ideal gradient under local conditions. The amplitude of local baselevel fluctuation caused by meander shifting and lateral planation is seen in the thickness of the alluvial-fan deposits. Were it not for these fluctuations, no true fans would develop except in response to possible accelerated erosion on the uplands. (In this connection, see King, 1949).

As pointed out by Lawson (1932) and by Wood (1942), the zone of maximum steepness becomes narrowed from both above and below. As this zone is worn back, the transportation surface (wash slope) leading to the valley floor rises against its lower edge while downwasting of the upland reduces its upper limit. In approach to mature dissection, valley widening in this manner and the expanding drainage net carry these wash slopes close to the corresponding network of divides, the limit being established by the local conditions governing the divide profile. The central Appalachian Plateau is still the classic example, and typical badlands are essentially the same except in scale and proportions. Height of the gravity slopes at this stage depends on available relief (Glock, 1932) and on texture of topography. These gravity slopes will remain the zone of most active erosion until the convexity of the lowered divides merges directly with the lower wash slopes. At that stage the gravity slopes as such are eliminated from the landscape, leaving only wash slopes. This should mark the full attainment of Davisian old-age topographic development. Peneplanation represents only the continued reduction of the wash slopes (Abflachungshänge).

SLOPE TYPES AS END MEMBERS

Ideally the terms gravity or derivation slope and wash slope should be defined in terms of the processes which they connote. But in practice it seems feasible to apply either term to those slopes or parts of slopes where the particular process is dominant, with perhaps minor occurrences of the other type. Thus the wash slopes in semi-arid and humid regions have innumerable small vegetation-controlled scarps or non-graded spots. Likewise gravity slope may apply to surfaces on which some graded rills occur. But where the proportion of such minor units approaches half-and-half, neither term should be used without appropriate qualification. As applied to broad slope areas, the terms represent end members of a gradational series, which thereby compels recognition of the minor component units (fig. 1).

In summary thus far, dissection of an upland to the stage of Davisian maturity in a humid climate greatly extends the area of gravity slopes along the valley walls. In further consequence of greater humidity, the stronger vegetational control of erosion results in gravity slopes that are less steep, and in wash slopes that are steeper than their respective equivalents in semi-arid regions. The wash slopes are therefore more vulnerable to gullying where vegetation weakens or fails, causing partial and temporary reversion to gravity slopes. Portions of the gravity and wash slopes become broken up into small and inconspicuous units that are further obscured by the everchanging pattern of vegetation, but that are nevertheless real and that have essential characteristics identical with such surfaces elsewhere. Wash-slope units predominate along the divides and, for the most part, control the lower valley-side slopes. Until well past maturity in the ideal Davisian cycle, the steepest parts of the valley sides are gravity slopes which diminish in prominence as they retreat. They disappear when the divides have been lowered sufficiently to come under the direct baselevel control of the valley floors (fig. 2).

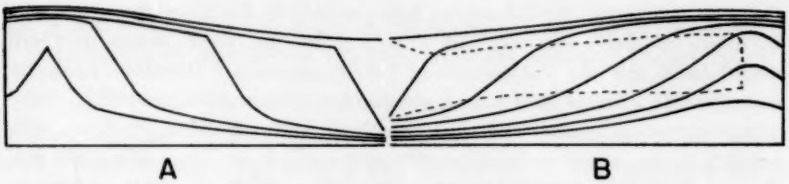


Fig. 2. Composite diagram representing valley-side profiles at successive stages in an ideal erosion cycle or sequence. Modified from Davis and from King.

A. Semi-arid grassland environment such as the western High Plains of the United States.

B. Humid environment of the "normal" Davisian cycle. Dashed line indicates zone of predominant gravity or derivation slopes, gradational to predominant wash slopes both above and below.

PENCKIAN-DAVISIAN COMPLEMENTS

The foregoing analysis shows that the fundamental landscape units developed by running water are derivation slopes and transportation slopes, and that these are present under humid as well as arid climatic conditions. The derivation or gravity slopes, wherever they occur, *tend* to maintain their characteristic gradients as they are worn back, the gradient being governed by local conditions of vegetation, if present, and by bedrock response to weathering.

Differences in gross aspects in the two contrasting climatic environments are basically those of unit size and distribution of the two fundamental landscape elements. Both are the less interrupted and therefore the more conspicuous where vegetation is scarce or absent, the effect of vegetation and greater humidity being to decrease the contrast in characteristic slope angle of the two, and to mingle the two types in small units on the slopes of intermediate average steepness. Progressive elimination of the small gravity slopes, with concomitant extension and integration of the wash-slope units, gives the overall effect of decreasing angle of valley-side slopes as downwasting of the divides goes on.

Therefore the essence of Penckian geomorphic principles amplifies and clarifies an aspect of running-water erosion which Davis left obscure. A possible reason for the long-continued obscurity may be the captivating contrast between aspects of arid- and humid-climate topography. Landscapes in humid climates are the more complex, and they have been treated without realizing that they are a composite of small, unlike elements which, in arid regions, occur as the gross or major units of the landscape. To perceive these slope elements in areas of humid climate requires close attention to details of the surface where erosion is in progress. The derisive caricature of a geomorphologist perched on a breezy hilltop and scanning the far horizon for another peneplain has been well earned; and yet perhaps it was inevitable in the development of a field so rich and varied.

PENEPLAIN AND PEDIPLAIN

With the foregoing analysis as a basis for interpretation, the penultimate land form has fundamentally the same topographic elements under any

climatic conditions, the differences being mostly in the proportions and distribution of those elements. In arid regions the wash slopes are well consolidated and the few remaining gravity slopes are therefore relatively conspicuous; whereas on a humid peneplain the wash slopes are still partially under vegetation control and show relatively more range in gradient, with possibly a few minor units of gravity slope still in evidence along the low divides. Each final hillside has become a unit wash slope, and the relatively large number of such units, because of the more complete drainage net, gives the landscape its characteristic undulatory aspect.

In humid regions the controlling baselevel in virtually all cases would be sea level. This is likewise true of many if not most of the extensive pediments now developing in southwestern United States which are graded to through-flowing, though intermittent, drainage lines. However, many of the African pedimented landscapes described by King (1953) apparently have no graded continuity to the sea, but have developed under local baselevel control.

In this connection it is significant that Davis (1909, ch. 10) regarded the uplands of eastern Montana as a typical peneplain now well started on a second erosion cycle. The surface of that semi-arid region bevels the simple sedimentary structure, with residual "lava-capped" buttes indicating the minimum thickness of strata thus beveled. It was this area that in 1883 confirmed the Davisian peneplain, and the interpretation of its development first enlivened for his students that which hitherto had been a dull and boresome subject.[3] To the present writer the butte scarps in that area are typical gravity slopes and the long wash slopes (the peneplain) are equally typical of graded transportation surfaces controlled by both vegetation and transport of sandy-silty sediment. Therefore it appears that Davis' type peneplain or "ultimate stage in the sequence of a simple cycle of development" (1909, ch. 10) has at least as much in common with the Arizona pediments as with the Harrisburg or any other demonstrable humid-climate peneplain. In accord with priority usage, all these near-plains of subaerial erosion should be included in the broad category of peneplains, though the arid-climate forms may constitute a pediplain class within the larger category.

Relatively resistant rock masses may become residual eminences on a low-relief landscape in any climate, whether by virtue of especially resistant lithology or merely a relative lack of jointing or other structural advantage. Due account must be taken of the fact that in many cases the degree of resistance to weathering depends as much on climate as on rock type. In so far as superior resistance to weathering can be demonstrated, the term monadnock would seem applicable to any conspicuous residual eminence, though the environment may indicate advisability of reference to a bornhardt or other type of monadnock. Further subdivision of the bornhardt type should be made where possible in order to distinguish between those having monad-

[3] Davis, W. M., unpublished communication to V. A. Rigdon.

nock qualities and those which are merely traces of drainage-divide heights (Penck's *Fernlinge*) and without relatively superior resistance to weathering.

CONCLUDING REMARKS

For purposes of topographic description and interpretation of subaerially produced topography, no better framework of reference than the erosion cycle of Davis has yet been devised. Historically it is only natural that humid-climate topography should have been considered first, although areally it is far surpassed by the arid and semi-arid types. However, the shortcomings of the Davis system appear to have been in the realm of detail recognition and correlation rather than in fundamentally limited applicability. A concept so useful cannot and should not be abandoned, though it must be augmented and improved where possible. In particular, the many varieties of stream-developed topography over the Earth should be considered from the standpoint of their similarities and common elements, so that their distinctive differences shall then be seen in proper systematic relationship in a single comprehensive and adequate scheme.

REFERENCES

Bryan, Kirk, 1922, Erosion and sedimentation in the Papago country, Arizona: U. S. Geol. Survey Bull. 730, p. 19-90.

Davis, W. M., 1905, The geographic cycle in an arid region: Jour. Geology, v. 13, p. 381-407.

———, 1909, Geographical essays: Boston, Ginn and Co. Reprinted 1954, New York, Dover Publications.

———, 1930, Rock floors in arid and humid climates: Jour. Geology, v. 38, p. 1-27, 136-158.

———, 1938, Sheetfloods and streamfloods: Geol. Soc. America Bull., v. 49, p. 1337-1416.

Fenneman, N. M., 1908, Some features of erosion by unconcentrated wash: Jour. Geology, v. 16, p. 746-754.

Frye, J. C., 1954, Graded slopes in western Kansas: Kansas Geol. Survey Bull. 109, pt. 6, p. 85-96.

Frye, J. C., and Smith, H. T. U., 1942, Preliminary observations on pediment-like slopes in the central High Plains: Jour. Geomorphology, v. 5, p. 215-221.

Gilluly, James, Waters, A. A., and Woodford, A. O., 1951, Principles of geology: San Francisco, W. H. Freeman Co.

Glock, W. S., 1932, Available relief as a factor in the profile of a land form: Jour. Geology, v. 40, p. 74-83.

Holmes, C. D., 1952, Stream competence and the graded stream profile: Am. Jour. Sci., v. 250, p. 899-906.

King, L. C., 1953, Canons of landscape evolution: Geol. Soc. America Bull., v. 64, p. 721-752.

King, P. B., 1949, The floor of the Shenandoah Valley: Am. Jour. Sci., v. 247, p. 73-93.

Lawson, A. C., 1932, Rain-wash erosion in humid regions: Geol. Soc. America Bull., v. 43, p. 703-724.

Mackin, J. H., 1948, Concept of the graded river: Geol. Soc. America Bull., v. 59, p. 463-511.

McGee, W J, 1897, Sheetflood erosion: Geol. Soc. America Bull., v. 8, p. 87-112.

Meyerhoff, H. A., 1940, Migration of erosion surfaces: Assoc. Am. Geographers Annals, v. 30, p. 247-254.

Penck, Walther, 1924, Die morphologische analyse: Stuttgart. (Translated by Hella Czech and K. C. Boswell, 1953, Morphological analysis of land forms: New York, St. Martin's Press).

Rich, J. L., 1938, Recognition and significance of multiple erosion surfaces: Geol. Soc. America Bull., v. 49, p. 1695-1722.

von Engeln, O. D., 1942, Geomorphology: New York, The Macmillan Co.

Wood, Alan, 1942, The development of hillside slopes: Geologists' Assoc. London Proc., v. 53, p. 128-140.

University of Missouri
Columbia, Missouri

[American Journal of Science, Vol. 253, July 1955, Pp. 391-417]

THE PETROCHEMISTRY OF SOME PRECAMBRIAN GRANITES OF WEST AFRICA, AND A PETROCHEMICAL COMPARISON WITH THE SVECOFENNIDE GRANITES OF FINLAND

VLADI MARMO

ABSTRACT. The chemical analyses of 60 West African granites have been plotted; they fall into two distinct petrochemical groups. The granites of these groups correspond in their chemical composition well to the syn- and late kinematic granites of the Svecofennide orogeny of Finland, and the group that overlaps in its petrochemistry the late kinematic field of Finnish granites can be definitely divided into sodic and potassic subgroups.

From the principle of the number of cations in the standard cell of a rock (Barth), the conclusion is reached that the West African granites corresponding in their petrochemistry to the synkinematic granites of Finland have in general less volume than the granites whose chemical composition is like that of Finnish late kinematic granites.

INTRODUCTION

The author, as a geologist in the Sierra Leone Geological Survey Department, had an opportunity to study the Precambrian granites of the Sula Mountains, Kangari Hills, and adjacent areas. Before that he had worked in the Svecofennide areas in Finland. From the first day he spent in the field in Sierra Leone, he observed striking similarities between the granites of the Sula Mountains and the Svecofennian granites of Finland. The similarities appeared both in the manner of occurrence of the rocks and in their mineralogical composition.

Judged from descriptions of West African granites, there are several areas similar to that of the Sula Mountains, and in general, the West African geologists (Dixey, 1925; Junner, 1930; Dixey and Willbourn, 1951; Pollett, 1951) considered these corresponding formations to be approximately of the same age as the "Birrimian" of the Gold Coast. The mentioned similarities in the field suggested a petrochemical study of West African "Birrimian" granites and a comparison between the Svecofennide (Finland) and "Birrimian" (West Africa) granites from the petrochemical point of view.

In this connection I take pleasure in expressing my sincere thanks to Mr. J. D. Pollett, Director of the Geological Survey Department of Sierra Leone, and to Mr. N. W. Wilson, the Assistant Director of the same Department, who enabled me to make the present study.

"ARCHEAN" AND "PRECAMBRIAN"

In Scandinavian usage the term "Precambrian" often covers all rocks older than Cambrian. "Archean" rocks are old Precambrian. In the Gold Coast Junner (1940, p. 7) suggests that the term "Archean" be used in the sense of Indian geologists (Holland and Fermor), hence covering the rocks below the great unconformity which, in India, separates "the unfossiliferous, slightly altered Purana formations—practically free from bathylithic intrusions of acidic igneous rocks—above the unconformity, from the ancient, foliated, and schistose igneous and sedimentary rocks below the unconformity." He wrote (1940, p. 7-8): " . . . the great unconformity between the Tarkwaian and Birrimian (in the Gold Coast) would be much more unlikely

to correspond with the Ep-Archaean unconformity of India than would be the unconformity at the end of the Tarkwaian. On either basis the Birrimians would be included in the Archaean." The rocks older than Cambrian but younger than the mentioned unconformity he collectively termed "pre-Cambrian." Kitson (1928) drew the boundary between Archaean and Precambrian below the Birrimians.

"SVECOFENNIDE" AND "BIRRIMIAN"

These two different conceptions have been purposely brought under the same heading because some controversy exists in the use of "Birrimian" in the publications dealing with the geology of West Africa.

Svecofennide is an ancient mountain chain in Scandinavia, occupying southwestern Finland and parts of southern Sweden. According to current opinion, the Svecofennide orogeny affected both the Svionian and the Bothnian formations, these being the oldest formations so far known and considered there. Hence the Svecofennide mountain chain is the oldest known in Fennoscandia (= Scandinavia + Finland + Russian Karelia).

The classification of the Precambrian (in the broad sense) rocks of West Africa is mainly based on the work of Kitson (1928) and Junner (1935) of the Gold Coast. Junner wrote (1940, p. 8): "The Archaean gneisses and schists (of Gold Coast) resemble closely the crystalline schists of Sierra Leone and are probably of the same age." The schists of the Sula Mountains of Sierra Leone are mainly considered to be younger than the "crystalline schists," and they are classified as belonging to the Birrimian formation (Dixey, 1925; Junner, 1930; Goloubinow, 1938; Dixey and Willbourn, 1951; Pollett, 1951; Bodin, 1951; etc.). This opinion, however, does not seem to be unanimous nowadays, since direct, dependable correlation of widely separated Precambrian areas is not possible in our present stage of knowledge.

The Birrimian means, in its original sense, a *formation* which (Kitson, 1928, p. 6) "comprises partially altered and normal rocks as slates, phyllites, flagstones, impure limestones, sandstones, grits and conglomerates, with their metamorphosed representatives—schists of various kinds, quartzites, hornstones, hornfelses and paragneisses." Junner (1935) divided the Birrimian into "Upper" and "Lower," consisting respectively (p. 17) "of metamorphosed lavas, pyroclastic and hypabyssal igneous rocks with bands of phyllites, graywackes, slates, and schists."

The first known (oldest) orogeny of West Africa took place, according to Junner (1940, p. 7), between the Birrimian and Tarkwaian and hence after Birrimian; such, presumably, covering both old formations: "Archaean gneisses and crystalline schists" and "Birrimian formation." Whether or not granites older than both these formations do occur is not without doubt.

It seems to the present author, however, that at least some French geologists consider as Birrimian the orogeny following both mentioned formations. When speaking of Birrimian granites they distinctly assume the intrusion of granites during the Birrimian orogeny. Bodin wrote (1951, p. 12): "La chaîne géosynclinale birrimienne, profondément érodée et érasée, criblée d'intrusions granitiques . . . " and thus definitely considers a "geosynclinal

Birrimian chain." The same opinion was also expressed by Mr. Marvier of French West Africa in a conversation with the present author, and also in his recent paper (1953). Bolgarsky (1950) considers Birrimian as a formation, using the heading "Tectonique birrimienne" (p. 19), but on the other hand, saying " . . . et que la grande majorité des granites et des gneiss était plissée avec le Birrimien," does not explain whether he considers the orogeny itself to be Birrimian or not.

CLASSIFICATION OF THE GRANITES

Sederholm initially divided the granites of the Svecofennide area of Finland into two groups:

Group 1—gneissose granites with a composition frequently approaching that of granodiorites. They form massifs concordant with the schistosity of the schist areas.

Group 2—more or less massive, often fine-grained granites, which tend to form migmatites.

Later he made a third subdivision. Group 3 granites did not differ very much in their composition from the granites of his group 2, but in the field they appeared distinctly younger than those of group 2.

Sederholm tried to use his granite classification to compare the Precambrian formations of Sweden and Finland but encountered difficulties in doing so because similar granites on the two sides of the Bothnian Gulf did not always fit into the age scheme based on his granite classification. It seemed that similar granites may be of different ages even in such a comparatively small area as formed by Scandinavia and Finland.

Eskola (1932) introduced the terms *synkinematic* and *late kinematic* to indicate that the granites of Sederholm's group 1 have originated during the earlier stage of the orogenic movements, and group 2 during the later stage of the same orogenic epoch. Also Wahl (1936a, 1936b) supposed that to each orogeny may be related two granite groups: the "older" and "younger" of Sederholm, according to Sederholm's earlier definition. The older are characterized by signs indicating their origin during an early stage of orogeny, and Wahl called them *primorogenic;* the younger, having in his opinion, originated in a later stage of orogeny, he called *serorogenic.* According to Wahl (1936b), the ratio of K_2O:CaO is characteristic. For his primorogenic granites it is < 1, for serorogenic > 2 (> 4). Thus Wahl assumed that any orogeny may contain two granites, and that these granites may be respectively similar in different orogenies. Hence, they must be tested separately for each orogeny.

In modern literature several authors have expressed the opinion that the synkinematic granites have originated by metasomatic processes and synkinematic granitization (see, for instance, Backlund, 1936, 1946; Perrin and Roubault, 1949; Reynolds, 1947). Read deals with the same question in several papers (1948, 1952) and, in setting up his "plutonic series," he distinctly pointed out the close relationship between older granites, metamorphism, and granitization.

TABLE 1
Analyses of West African Granitic Rocks

No.	Description	Locality	Authority	Analyst
1	Biotite-muscovite granite. J 15 500	Kumasi Dist., Gold Coast	Junner and James (1947)	H. L. Riley
2	Biotite granite. J 933	Winneba, Gold Coast	"	"
3	Porphyritic biotite granite. J 3238	Busarowa, N. Terr., Gold Coast	"	"
4	Pinkish quartz-rich biotite granite. J 3197	Winneba, Gold Coast	"	"
5	Similar to J 3197, dike in it. J 3198	Winneba, Gold Coast	"	"
6	Similar to J 3197, dike in it. J 3199	Winneba, Gold Coast	"	"
7	Porphyritic biotite granite. H 3608	Ashanti, Axim Dist., Gold Coast	"	Miss R. C. Graves
8	Soda granite. J 15638	Obuasi, Gold Coast	"	H. L. Riley
9	Sodic hornblende-biotite granite. J 2360	Axim Dist., Gold Coast	"	W. H. Bennett
10	Saussuritic soda-rich granite. J 1468	Dixcove, Axim Dist., Gold Coast	"	H. F. Harwood
11	Granodiorite. J 1192	Goaso, Ashanti, Gold Coast	"	"
12	Sodic granite porphyry. J 96	Obuasi, Gold Coast	"	W. H. Bennett
13	Gneissic granodiorite. J 1553	Masapo-Bombirri, Gold Coast	"	"
14	Porphyritic biotite granite. J 1519	Akrokeri mine, Gold Coast	"	"
15	Biotite granite. J 1503	Akrokeri mine, Gold Coast	"	"
16	Biotite-hornblende granite. 3113	French Guinea	Bodin (1951, p. 33)	P. Rose
17	Biotite-hornblende granite. 4785	Senegal	" (1951, p. 33)	B. Martinet
18	Porphyritic granodiorite. 1696	Mankono, French Guinea	" (1951, p. 34)	J. Patureau
19	Porphyritic biotite granite. 4679	Haute Volta	" (1951, p. 35)	"
20	Porphyritic biotite-hornblende granodiorite. 5097	Segnéla, Ivory Coast	" (1951, p. 36)	B. Martinet
21	Granitized amphibolite. 4583	Marehorie	" (1951, p. 40)	J. Patureau
22	Biotite-hornblende granodiorite. 1874	Golé, Ivory Coast	" (1951, p. 52)	"
23	Granodiorite. 1985	Koumbia, Haute Volta	" (1951, p. 54)	"
24	Quartz diorite. 1600	Lome, Moyenne, Ivory Coast	" (1951, p. 54)	"
25	Granodiorite. 634	Basse, Ivory Coast	" (1951, p. 55)	"
26	Granodiorite. 1192	Basse, Ivory Coast	" (1951, p. 55)	W. H. Bennett
27	Granodiorite. 4703	Haute Gambia	" (1951, p. 57)	P. Rose
28	Microgranodiorite. 3903	Haute Gambia	" (1951, p. 59)	J. Patureau
29	Akeritic granite. 4792	Haute Volta	" (1951, p. 62)	B. Martinet
30	Akeritic granite. 2340	Haute Volta	" (1951, p. 63)	J. Patureau

TABLE 1
Analyses of West African Granitic Rocks

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O-	Total
72.59	0.12	15.18	0.13	1.01	0.02	0.45	1.17	3.86	4.52	0.27	0.71	0.14	100.20*
67.00	0.58	15.86	0.81	2.62	0.03	0.96	3.04	3.61	3.64	0.16	1.15	0.21	99.82*
68.46	0.48	15.39	0.80	2.00	0.04	1.02	2.98	4.40	3.13	0.17	0.98	0.19	100.21*
73.53	0.09	14.95	0.86	0.16	0.06	0.39	0.97	3.78	4.52	0.05	0.48	0.17	100.12*
74.16	0.05	14.49	0.59	0.33	0.02	0.33	1.09	3.58	4.32	0.03	0.58	0.17	99.88*
72.65	0.11	14.72	0.80	0.32	0.02	0.35	1.28	4.48	4.08	0.05	0.56	0.20	99.76*
68.57	0.34	16.01	1.06	1.48	0.03	0.77	2.47	5.14	2.96	0.12	0.68	0.12	99.93*
72.34	0.08	14.52	0.13	0.75	0.06	0.47	1.72	6.13	1.85	0.27	0.66	0.10	99.88*
70.58	0.23	14.78	1.08	1.17	0.07	1.23	2.05	4.66	2.42	0.05	1.13	0.29	99.89*
64.44	0.32	17.82	1.94	1.33	0.07	1.14	5.12	5.06	1.29	0.16	1.70	0.08	100.58*
64.79	0.46	16.16	2.17	1.48	0.07	2.10	3.75	4.70	2.54	0.18	1.48	0.34	100.23*
63.06	0.30	15.51	0.02	3.00	0.06	2.13	4.25	4.14	0.94	0.19	1.12	0.10	100.07*
62.00	0.60	13.94	1.25	4.38	0.10	4.72	5.18	3.54	2.19	0.24	1.64	0.20	100.24*
65.14	0.55	16.49	0.42	2.94	0.05	2.56	3.63	3.11	2.25	0.26	1.36	0.23	99.83*
64.29	0.55	15.36	0.83	2.94	0.06	2.31	3.70	4.33	3.19	0.25	1.32	0.09	99.92*
67.96	0.70	15.20	1.54	2.12		1.41	3.10	3.60	3.48	0.15	0.32	0.19	99.77
62.90	0.80	15.38	1.50	4.00		3.10	4.50	4.85	1.80	0.22	0.70	0.10	100.10
72.02	0.20	15.57	1.92	1.00	0.07	0.61	1.94	2.83	2.40	0.09	0.08	0.02	99.93
72.10	0.35	13.05	1.60	1.17	0.01	2.35	2.45	2.65	3.85	0.07	0.50	0.10	100.25
69.65	0.30	15.70	0.65	1.30		1.45	1.80	3.55	5.35	0.12	0.44	0.12	100.43
61.37	0.60	17.10	2.65	3.60	0.10	3.50	6.10	2.55	1.94	0.30	0.22	0.20	100.18
70.70	0.32	14.05	1.95	1.25	0.02	1.45	2.90	3.55	2.65	0.09	0.38	0.23	99.54
68.07	0.75	15.05	1.43	2.76	0.08	1.94	4.12	2.95	2.40	0.15	0.13	0.40	100.25
57.60	0.47	17.70	3.30	4.25	0.10	3.15	6.95	2.90	1.60	0.06	1.75	0.20	100.13
65.45	0.30	15.60	1.84	2.44	0.07	2.47	4.10	4.50	2.12	0.10	0.70	0.02	99.71
64.79	0.46	16.16	2.17	1.48	0.07	2.10	3.75	4.70	2.54	0.18	1.48	0.34	100.22
63.10	0.33	16.45	1.56	2.48		2.10	5.30	4.20	2.60	0.18	1.20	0.17	99.77
67.19	0.30	16.19	1.82	1.58	0.14	1.57	3.57	3.60	2.40	0.12	0.23	0.25	99.66*
68.90	0.25	14.35	1.30	1.80		0.75	2.80	6.00	1.20	0.16	0.05	0.35	99.66
76.20	0.35	11.65	1.90	0.78	0.04	0.28	2.05	3.60	2.75	0.04	0.55	0.25	100.44

TABLE 1 (Continued)

No.	Description	Locality	Authority	Analyst
31	Biotite-amphibole granite. 1748	Ivory Coast	" (1951, p. 33)	B. Martinet
32	Biotite-chlorite granite.	Mont Oursa, French Guinea	" (1951, p. 31)	J. Patureau
33	Biotite granite. 3119	Famorea sur la Niger, French Guinea	" (1951, p. 31)	P. Rose
34	Biotite granite. 1031	Segnéla, Ivory Coast	" (1951, p. 31)	B. Martinet
35	Muscovite-biotite granite. 4737	Bouaké, AOF	" (1951, p. 29)	J. Patureau
36	Muscovite-biotite granite. 4756	Saraya, Senegal	" (1951, p. 29)	P. Rose
37	Muscovite-biotite granite. 4739	Bouaké	" (1951, p. 25)	J. Patureau
38	Akeritic granite. 4683	Ouéré, Haute Volta	" (1951, p. 63)	"
39	Sodic granite. 3265	Kekoro	" (1951, p. 64)	B. Martinet
40	Monzonitic granite. 5089	long. 6°46′W; lat. 11°50′N	" (1951, p. 65)	"
41	Monzonitic granite. 536	Basse, Ivory Coast	" (1951, p. 65)	J. Patureau
42	Monzonitic granite. K	Ivory Coast	" (1951, p. 66)	"
43	Monzonitic granite. 4748	Haute Volta	" (1951, p. 67)	B. Martinet
44	Charnockite.	Gbon, Djola, Ivory Coast	Obermuller (1941, p. 39)	
45	Porphyritic granodiorite	Yomen, Ivory Coast	" (1941, p. 43)	P. Rose
46	Biotite granite	Baradou, Ivory Coast	" (1941, p. 43)	
47	Biotite granite	Poste de Makenta	" (1941, p. 42)	
48	Biotite gneiss	2 km east of Sierra Leone frontier	" (1941, p. 42)	
49	Granodiorite	19 km southwest of Makenta	" (1941, p. 42)	
50	Granodiorite	Yarakoldoro, Ivory Coast	" (1941, p. 42)	
51	Biotite granodiorite gneiss	G'Béké, Ivory Coast	" (1941, p. 66)	P. Rose
52	Mylonitic biotite gneiss	Mabossou, Ivory Coast	" (1941, p. 67)	"
53	Leucocratic banded gneiss. K 150	Osi area, Nigeria	King and Swardt (1949, p. 20)	W. H. Bennett
54	Granite gneiss. A 28	Osi area, Nigeria	" (1949, p. 20)	"
55	Coarse porphyritic granite. K 115	Osi area, Nigeria	" (1949, p. 20)	"
56	Aplogranite. K 50	Osi area, Nigeria	" (1949, p. 20)	L. C. Chadwick
57	Granite	Makong, Sierra Leone	Rep. of Min. Geol. Surv. Deptm. Sierra Leone (1930-1931, p. 10)	
58	Leucocratic biotite granite. 1638-3233	Irigle, Ivory Coast	Bolgarsky (1950, p. 43)	P. Rose
59	Biotite-amphibole granite. 199-4344	Gouékan, Ivory Coast	" (1950, p. 44)	B. Martinet
60	Leucocratic granite. 1622-3233	Namarakouma, Ivory Coast	" (1950, p. 45)	P. Rose

* See supplementary table 1-A below for minor elements.

TABLE 1 (Continued)

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O-	Total
66.35	0.60	15.00	0.85	2.70		2.10	3.50	4.40	2.00	0.26	0.75	0.35	99.56*
68.30	0.30	15.58	1.80	1.85		1.32	3.85	2.35	3.40	0.10	0.10	0.70	99.65
72.52	0.36	14.10	1.57	0.70		0.51	1.36	3.01	5.10	0.01	0.40	0.10	99.65
73.90	0.30	12.90	1.40	0.80		0.45	1.05	2.60	6.20	0.10	0.28	0.13	100.11
73.02	0.25	14.13	1.04	1.00	0.03	1.05	1.62	2.65	4.80	0.13	0.12	0.30	100.17
70.40	0.10	14.35	2.00	0.62		0.65	1.90	3.78	4.93	0.13	1.23	0.35	100.44
73.25	0.20	15.25	0.77	0.57	0.03	0.19	1.21	2.46	5.50	0.02	0.12	0.30	99.87
70.25	0.35	14.50	1.09	0.99	0.06	1.04	3.00	5.70	2.85	0.15	0.60	0.20	100.78
73.65	0.10	14.10	0.80	1.25		0.20	1.05	6.60	1.70	0.20	0.45	0.10	100.20
70.10	0.45	15.00	1.55	1.50		0.30	1.10	4.55	4.60	0.15	0.60	0.25	100.15
75.80	0.20	12.55	0.70	1.73	0.04	0.24	1.50	3.10	3.30	0.01	0.35	0.30	99.82
67.76	0.68	15.34	1.52	2.10	0.08	1.40	3.08	3.58	3.68	0.19	0.31	0.19	99.91
76.20	0.15	12.10	0.65	1.65		0.17	0.94	3.22	4.35		0.30	0.23	99.96
71.80	0.16	14.90	1.10	1.08	n.d.	0.39	2.20	4.17	4.11		0.60		100.51
71.13	0.22	14.58	1.01	0.72		0.49	1.80	5.60	2.46		0.87		98.88
73.48	0.28	13.87	1.12	0.80		0.22	2.26	5.43	2.20	0.12	0.15		99.93
70.93	0.30	15.91	1.42	0.71		0.78	3.32	4.37	1.83	0.18	0.22	0.05	100.02
71.40	0.32	15.35	1.42	0.82		0.30	1.78	5.70	1.80	0.15	0.60		99.64
71.03	0.20	16.26	1.05	0.70		0.47	2.30	4.87	1.82		0.50		99.20
70.30	0.22	16.40	1.10	0.72		0.72	2.80	5.53	2.01	0.05	0.32	0.05	100.22
65.55	0.12	19.30	0.42	2.93	=	1.40	4.05	3.82	1.66	0.14	0.74	0.16	100.29
74.55	0.18	14.85	0.22	0.70	0.05	0.68	2.88	1.40	3.62		0.52	0.17	99.82
70.70	0.48	13.79	0.83	1.77	0.03	0.87	1.83	2.83	5.74	0.13	0.65	0.04	100.09*
64.30	0.95	14.99	1.50	3.90	0.13	1.06	2.83	3.17	5.53	0.29	0.89	0.12	100.19*
69.49	0.41	14.65	0.82	1.82	0.03	0.65	1.72	2.95	6.54	0.13	0.60	0.09	100.21*
72.25	0.23	14.02	0.59	1.25	0.04	0.54	1.40	3.00	5.86	0.05	0.46	0.09	99.98*
74.88	0.045	14.98	0.26	0.40	0.22	0.04	0.90	4.88	2.98	0.06	0.46	0.05	100.165*
72.47	0.19	14.16	0.94	0.90		1.78	0.25	7.08	1.28	tr.	0.52		99.60
71.05	0.90	15.10	1.19	1.44		2.82	0.60	4.85	1.90	"	0.60		100.45
73.00		15.50		0.18			1.12	4.83	5.02		0.28		99.55

TABLE 1-A
Minor Elements in West African Granitic Rocks

No.	Description	Locality	Authority	Analyst
1	Biotite-muscovite granite. J 15 500	Kumasi Dist., Gold Coast	Junner and James (1947)	H. L. Riley
2	Biotite granite. J 933	Winneba, Gold Coast	"	"
3	Porphyritic biotite granite. J 3238	Busarowa, N. Terr., Gold Coast	"	"
4	Pinkish quartz-rich biotite granite. J 3197	Winneba, Gold Coast	"	"
5	Similar to J 3197, dike in it. J 3198	Winneba, Gold Coast	"	"
6	Similar to J 3197, dike in it. J 3199	Winneba, Gold Coast	"	"
7	Porphyritic biotite granite. H 3608	Ashanti, Axim Dist., Gold Coast	"	Miss R. C. Graves
8	Soda granite. J 15638	Obuasi, Gold Coast	"	H. L. Riley
9	Sodic horneblende-biotite granite. J 2360	Axim Dist., Gold Coast	"	W. H. Bennett
10	Saussuritic soda-rich granite. J 1468	Dixcove, Axim Dist., Gold Coast	"	H. F. Harwood
11	Granodiorite. J 1192	Goaso, Ashanti, Gold Coast	"	"
12	Sodic granite porphyry. J 96	Obuasi, Gold Coast	"	W. H. Bennett
13	Gneissic granodiorite. J 1553	Masapo-Bombirri, Gold Coast	"	"
14	Porphyritic biotite granite. J 1519	Akrokeri mine, Gold Coast	"	"
15	Biotite granite. J 1503	Akrokeri mine, Gold Coast	"	"
16	Biotite-hornblende granite. 3113	French Guinea	Bodin (1951, p. 33)	P. Rose
17	Biotite-hornblende granite. 4785	Senegal	" (1951, p. 33)	B. Martinet
18	Porphyritic granodiorite. 1696	Mankono, French Guinea	" (1951, p. 34)	J. Patureau
19	Porphyritic biotite granite. 4679	Haute Volta	" (1951, p. 35)	"
20	Porphyritic biotite-hornblende granodiorite. 5097	Segnéla, Ivory Coast	" (1951, p. 36)	B. Martinet
21	Granitized amphibolite. 4583	Marehorie	" (1951, p. 40)	J. Patureau
22	Biotite-hornblende granodiorite. 1874	Golé, Ivory Coast	" (1951, p. 52)	"
23	Granodiorite. 1985	Koumbia, Haute Volta	" (1951, p. 54)	"
24	Quartz diorite. 1600	Lome, Moyenne, Ivory Coast	" (1951, p. 54)	"
25	Granodiorite. 634	Basse, Ivory Coast	" (1951, p. 55)	"
26	Granodiorite. 1192	Basse, Ivory Coast	" (1951, p. 55)	W. H. Bennett
27	Granodiorite. 4703	Haute Gambia	" (1951, p. 57)	P. Rose
28	Microgranodiorite. 3903	Haute Gambia	" (1951, p. 59)	J. Patureau
29	Akeritic granite. 4792	Haute Volta	" (1951, p. 62)	B. Martinet
30	Akeritic granite. 2340	Haute Volta	" (1951, p. 63)	J. Patureau

TABLE 1-A
Minor Elements in West African Granitic Rocks

BaO	SrO	ZrO_2	Cr_2O_3	LiO2	Rare Earth	V_2O_5	CO_2	F	Cl	S	Less O for S, F
									tr.	0.05	0.02
0.12	0.01			tr.					tr.	0.03	0.01
0.12	0.04			tr.					tr.	0.01	
0.10										0.01	
0.13										0.01	
0.13										0.01	
0.16							n. d.			0.03	0.01
tr.	tr.						0.77		tr.	0.04	0.01
0.11		0.02	tr.							0.04	0.02
0.08	0.01	tr.		tr.			none		0.01	0.02	0.01
			tr.			tr.	n. d.			0.01	
							5.06			0.19	
0.01			0.02			0.01	0.20			0.03	0.01
0.10			0.01			0.01	0.71			0.02	
0.13			0.01			0.01	0.30			0.25	
							0.25				
							0.70				

TABLE 1-A (Continued)

No.	Description	Locality	Authority	Analyst
31	Biotite-amphibole granite. 1748	Ivory Coast	" (1951, p. 33)	B. Martinet
32	Biotite-chlorite granite.	Mont Oursa, French Guinea	" (1951, p. 31)	J. Patureau
33	Biotite granite. 3119	Famorea sur la Niger, French Guinea	" (1951, p. 31)	P. Rose
34	Biotite granite. 1031	Segnéla, Ivory Coast	" (1951, p. 31)	B. Martinet
35	Muscovite-biotite granite. 4737	Bouaké, AOF	" (1951, p. 29)	J. Patureau
36	Muscovite-biotite granite. 4756	Saraya, Senegal	" (1951, p. 29)	P. Rose
37	Muscovite-biotite granite. 4739	Bouakaé	" (1951, p. 25)	J. Patureau
38	Akeritic granite. 4683	Ouéré, Haute Volta	" (1951, p. 63)	"
39	Sodic granite. 3265	Kekoro	" (1951, p. 64)	B. Martinet
40	Monzonitic granite. 5089	long. 6°46′W; lat. 11°50′N	" (1951, p. 65)	"
41	Monzonitic granite. 536	Basse, Ivory Coast	" (1951, p. 65)	J. Patureau
42	Monzonitic granite. K	Ivory Coast	" (1951, p. 66)	"
43	Monzonitic granite. 4748	Haute Volta	" (1951, p. 67)	B. Martinet
44	Charnockite.	Gbon, Djola, Ivory Coast	Obermuller (1941, p. 39)	
45	Porphyritic granodiorite	Yomen, Ivory Coast	" (1941, p. 43)	P. Rose
46	Biotite granite	Baradou, Ivory Coast	" (1941, p. 43)	
47	Biotite granite	Poste de Makenta	" (1941, p. 42)	
48	Biotite gneiss	2 km east of Sierra Leone frontier	" (1941, p. 42)	
49	Granodiorite	19 km southwest of Makenta	" (1941, p. 42)	
50	Granodiorite	Yarakoldoro, Ivory Coast	" (1941, p. 42)	
51	Biotite granodiorite gneiss	G'Béké, Ivory Coast	" (1941, p. 66)	P. Rose
52	Mylonitic biotite gneiss	Mabossou, Ivory Coast	" (1941, p. 67)	"
53	Leucocratic banded gneiss. K 150	Osi area, Nigeria	King and Swardt " (1949, p. 20)	W. H. Bennett
54	Granite gneiss. A 28	Osi area, Nigeria	" (1949, p. 20)	"
55	Coarse porphyritic granite. K 115	Osi area, Nigeria	" (1949, p. 20)	"
56	Aplogranite. K 50	Osi area, Nigeria	" (1949, p. 20)	L. C. Chadwick
57	Granite	Makong, Sierra Leone	Sierra Leone Dept. Min. Geol. Survey Rept. (1930-1931, p. 10)	
58	Leucocratic biotite granite. 1638-3233	Irigle, Ivory Coast	Bolgarsky (1950, p. 43)	P. Rose
59	Biotite-amphibole granite. 199-4344	Gouékan, Ivory Coast	" (1950, p. 44)	B. Martinet
60	Leucocratic granite. 1622-3233	Namarakouma, Ivory Coast	" (1950, p. 45)	P. Rose

TABLE 1-A (Continued)

BaO	SrO	ZrO_2	Cr_2O_3	LiO2	Rare Earth	V_2O_5	CO_2	F	Cl	S	Less O for S, F
							0.70				
0.15	0.007	0.04	n.d.	0.03	0.05		0.07	0.08		0.03	0.05
0.14	0.009	0.09	n.d.	0.02	0.04		0.17	0.10		0.03	0.06
0.11	0.006	0.04	n.d.	0.02	0.04		0.06	0.03		0.03	0.04
0.08	0.005	0.02	n.d.	0.02	0.03		n. d.	0.06		0.05	0.05
				tr.	NiO:tr.				0.01		

In the opinion of the present author, among the synkinematic granites (to a minor extent, however) there also are elements of igneous origin, the results of intrusion of palingenetic melt.

Read and many others consider the existence of younger granites to be probably of intrusive character, this conclusion being rejected by the modern French school (Perrin and Roubalt, 1950), but an idea which is fully compatible with the findings of the present author obtained from the granites of the Sula Mountains (Marmo, 1954).

PETROCHEMISTRY OF THE GRANITES OF WEST AFRICA

As Simonen has shown (1948), there occur distinct differences in the chemical composition of syn- and late kinematic granites of the Svecofennide orogeny of Finland. Whether the syn- and late kinematic granites of different orogenies are respectively similar or not has not yet been ascertained; it is likely, however, that different orogenies may have different granites, the syn- and late kinematic groups still being, in each case, distinguishable from each other.

The present author considered that comparison of the petrochemistries of the older West African and Svecofennide, widely separated, granites would be profitable for the granite problem in West Africa.

For this petrochemical study of West African granites the analyses were plotted from the publications of several authors (Bodin, 1951; Bolgarsky, 1950, Hirst, 1942; Junner and James, 1947; Obermuller, 1941) who have described the West African granites; they considered them to be Birrimian. In addition, some analyses of the granites of Nigeria, Osi area (King and de Swardt, 1949) and one of Sierra Leone have been taken into consideration.

Bodin (1951) has investigated the French West African granites from the chemical point of view, but in his excellent paper he discusses them from the point of view of magma differentiation, and he studies the granites from each batholith separately. Bodin does distinguish two granites as well, a classification which is also used by Marvier (1953). They distinguish between the granites of concordant and discordant batholiths. The former tend to be rich in potassium; the latter are predominantly sodic, generally approaching granodiorites in composition, according to Bodin. He considers the concordant batholiths to be syntectonic, the discordant ones post-tectonic, and remarks that the former granites are similar to the synkinematic granites (1951, p. 89). From the descriptions of the granites, however, it seems to be evident that their classification is not based on the same criteria as that used in distinguishing syn- and late kinematic granites; and from the evidence from Sierra Leone, it can definitely be said that in the same batholith both syn- and late kinematic granites may occur, the latter forming veins cutting the former, or forming domelike intrusions with synkinematic shells (Marmo, 1954).

In the present study the petrochemistry of the Birrimian granites is tested in order to find separate petrochemical groups that correspond to the syn- and late kinematic granites of the Svecofennide orogeny of Finland (Simonen,

1948). In each group considerable variation in the chemical composition should still be allowed.

DESCRIPTION OF GRAPHS

The elements of chemical composition of the granites chosen for discussion.—In table 1 all analyses obtained from the above-mentioned publications are given. Table 2 contains the Niggli values (al, fm, c, and alk) of the same analyses, and table 3 gives the values of $\frac{Na_2O\ K_2O\ mol}{CaO\ mol} = \frac{alk}{c}$ relative molecular ratio K_2O:Na_2O, and relative molecular values for (K_2O Na_2O) and SiO_2.

The ratio $\frac{alk}{c}$ is characteristic for granites and shows the relative abundance of the lime minerals (especially anorthite) and alkali minerals (especially alkali feldspars) in the granites. The relative molecular ratio of $\frac{K_2O}{Na_2O}$ is considered to be necessary, because the author observed that, at least within the late kinematic granites of the Sula Mountains, Sierra Leone, both sodic and potassic varieties occur. In figure 1 a variation diagram is shown, where abscissa = weight percentage of SiO_2; ordinate = weight percentage of CaO and of (Na_2O + K_2O). The dotted curves include the area of distribution of alkali values, the stippled curves that of CaO. The full lines intersect at SiO_2 = 62.5. If in the diagram the granites belong to different "variation series," all particular series are characterized by an intersection point of calc and alkali lines within the area ABCD, that is, corresponding to SiO_2-values between 61 and 65.5. These values are Peacock's (see Barth, 1952, p. 172) "alkali-lime indexes." Hence the granites considered

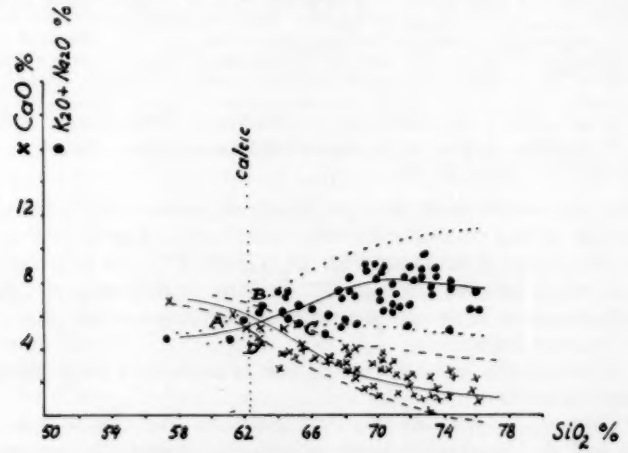


Fig. 1. Variation diagram of the West African Birrimian granites. Area ABCD includes the most of intersection points of lime and alkali curves of granites. The abscissae indicate also the lime-alkali indexes of Peacock.

in the present study belong to series with alkali-lime index not less than 61 and not more than 65.5. That is, at least most of the granites here belong to the calcic suite. As will be shown on pages 410-411, certain West African Precambrian granites do not belong to this suite.

The relationship of $\frac{Na_2O\ K_2O}{CaO}$ *to the relative molecular value of* SiO_2*.*—In figure 2 the relationship between $\frac{Na_2O\ K_2O}{CaO}$ and SiO_2 (rel. mol.) is graphically illustrated. The granites having a high value of $\frac{NaO\ KO}{CaO}$ are rich in quartz as well, and all granites having this ratio greater than 3.5 do not contain SiO_2 (rel. mol.) less than 116. To this category belong the granites 1, 4, 5, 6, 8, 33, 34, 37, 39, 40, 43, 45, 56, 57, 59 and 60. The 20

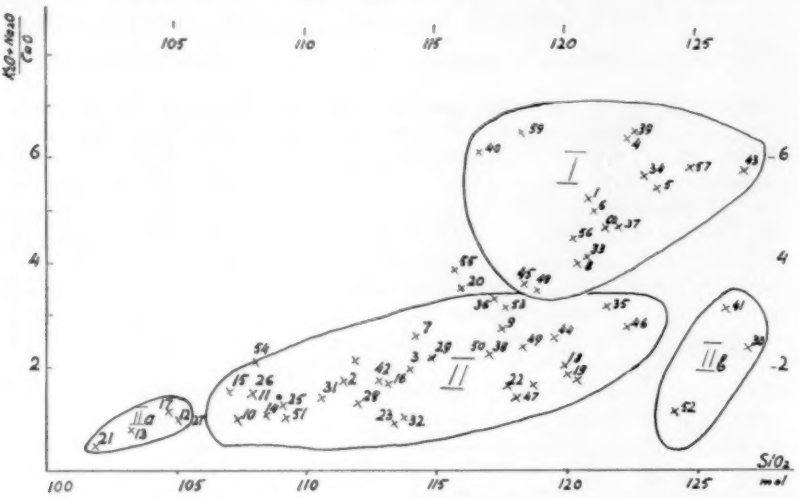


Fig. 2. Variation diagram of the ratio alkali:lime against the silica. I, II, IIa, and IIb are provisionally formed groups.

and 48 are just on the limit. This group may be provisionally called group 1.

Granites having an alkali-lime ratio less than 3.5 may be rich in quartz (30, 41, 52), or poor in quartz (12, 13, 17, 21, 27), the SiO_2 (rel. mol.) having all values between 102 and 127. Granites of this category will provisionally form group 2, the subgroups 2a and 2b corresponding to low and high SiO_2 content respectively.

Such grouping is quite empirical, and is made only to obtain a basis for further discussion.

Comparison of al with si.—Figure 3 shows the relationships of the Niggli values al and si. The granites cover an elongated area in diagonal position to the axes of the graph, and both values increase together. Simonen's graph (1948, p. 10) for Svecofennide granites is very similar to that of figure 3.

Magnusson has studied petrochemically the so-called "urgranites" of Sweden, and the area occupied by Swedish granites (according to Magnusson) is shown from Simonen, 1948, as well. From the graph it can be seen that, in general, the West African granites are richer in al than the "urgranites" of Central Sweden, but their composition is in better agreement with the Finnish Svecofennide granites.

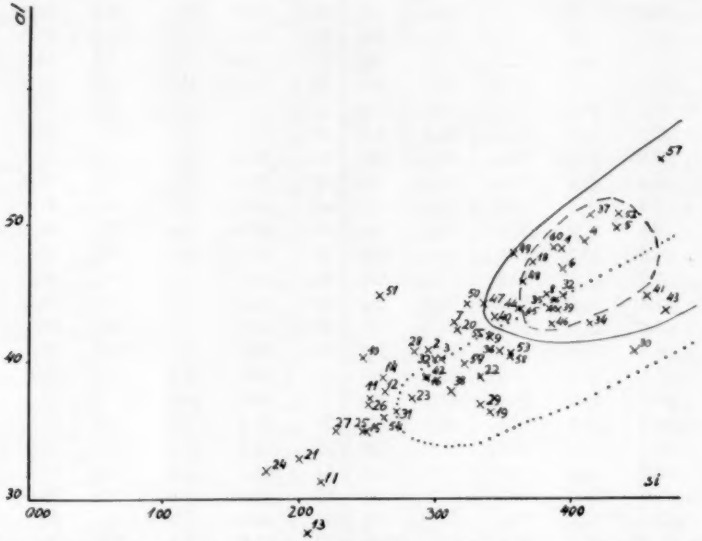


Fig. 3. Relations of al and si in the West African Birrimian granites. The full line shows the West African granites, which approach in chemical composition the Svecofennide late kinematic granites. The stippled line indicates the late kinematic field of the Svecofennide granites, according to Simonen (1948). The thinly stippled line shows the field of Swedish "urganites," after Magnusson (taken from Simonen, 1948).

After comparing the distribution of West African granites on the graphs of figures 2 and 3, one can see that the provisionally formed group 1 of figure 2 roughly occupies in the graph of figure 3 the corner rich in both al and si. In the same figure is also shown the area of Svecofennian late kinematic granites (according to Simonen), and within this area come the following West African granites: 1, 4, 5, 6, 8, 18, 33, 35, 37, 39, 46, 48, 52, 56, 60. They all belong to group 1 of figure 2, except 35 and 46, which are in figure 2 close to the area of group 1, and 52, which lies there in the area "2b" and 18 in the middle of "2."

The granites of the provisional group 1, 18, 34, 40, 43 and 45 lie just outside the line of the late kinematic area of Simonen; 57 takes position of a rock exceptionally rich in Al and SiO_2, and 59 takes place within the syn-kinematic area of Simonen.

Group 2a (fig. 2), extremely poor in quartz, has disappeared in figure 3; 13 and 17 show, however, exceptionally low al and si. The second excep-

TABLE 2

Niggli Values of West African Granites (numeration that of table 1)

No.	al	fm	c	alk	si	No.	al	fm	c	alk	si
1	48.5	8.5	7.0	36.0	394	31	36.5	25.0	15.5	23.0	272
2	41.0	19.0	14.5	25.5	295	32	40.5	22.0	18.0	19.5	301
3	40.5	17.0	14.5	28.0	306	33	45.0	14.0	8.0	33.0	394
4	49.0	8.5	6.0	36.5	411	34	43.0	14.0	6.5	36.5	414
5	50.0	7.0	7.0	36.0	435	35	44.0	16.5	9.5	30.0	387
6	47.0	8.0	7.5	37.5	395	36	41.0	15.0	11.0	33.0	348
7	43.0	14.0	12.0	31.0	313	37	51.0	8.0	7.0	34.0	416
8	45.0	7.5	10.0	37.5	382	38	38.0	15.0	14.0	33.0	313
9	42.0	18.0	10.5	29.5	341	39	44.0	10.5	6.0	39.5	391
10	40.5	16.0	21.5	22.0	249	40	43.5	14.5	6.0	36.0	344
11	37.0	23.5	15.5	24.0	253	41	45.0	14.0	10.0	31.0	457
12	38.0	23.5	19.0	19.5	263	42	39.0	21.5	14.5	25.0	294
13	27.5	38.5	18.0	16.0	207	43	44.0	13.0	6.0	37.0	470
14	39.0	27.0	16.0	18.0	263	44	44.0	17.0	12.0	33.0	361
15	35.0	25.5	15.0	24.5	250	45	44.0	10.5	10.0	35.5	364
16	39.0	21.5	14.5	25.0	294	46	43.0	9.5	12.5	35.0	387
17	31.5	31.5	17.0	20.0	218	47	44.5	13.5	17.0	25.0	337
18	49.0	17.0	11.5	22.5	384	48	46.0	11.0	9.5	33.5	365
19	36.5	27.0	12.5	24.0	342	49	48.0	10.5	12.0	29.5	358
20	42.5	17.0	9.0	31.5	317	50	44.5	11.5	14.0	30.0	324
21	33.0	34.0	21.0	12.0	200	51	45.0	19.5	17.0	18.5	260
22	39.0	22.0	15.0	24.0	334	52	51.0	9.5	18.0	21.5	437
23	37.5	27.0	18.0	18.5	283	53	41.0	17.0	10.0	32.0	358
24	32.0	33.0	23.0	12.0	176	54	36.0	24.0	12.5	27.5	262
25	35.0	26.0	17.0	22.0	248	55	42.0	15.0	8.5	34.5	340
26	37.0	23.5	15.5	24.0	251	56	44.0	12.0	8.0	36.0	387
27	35.0	23.0	20.5	21.5	228	57	51.5	4.5	5.5	38.5	436
28	41.0	21.5	16.0	21.5	286	58	41.0	20.0	1.0	38.0	356
29	37.0	18.0	14.0	31.0	334	59	40.0	30.0	4.0	26.0	322
30	41.0	15.0	13.0	31.0	448	60	48.5	0.5	9.0	42.0	388

tional group of graph 2, group 2b, is in figure 3, close to (41) or within (52) the late kinematic area of Simonen.

The ratio K_2O:Na_2O.—As mentioned on page 403, among the late kinematic granites of the Sula Mountains both sodic and potassic varieties occur (Mr. Marvier, in conversation with the author, reported that the probably late kinematic Precambrian granites of French West Africa are in general sodic). The synkinematic granites mostly approach the granodiorites in composition, and have the $Na_2O:K_2O>1$. Hence, if a graph showing the variations in the mentioned ratio were constructed, and if the observations from the Sula Mountains could be generalized, the granites of the late kinematic area in figure 3 should be split into two groups—sodic and potassic—on the new graph. For other granites such splitting is not to be expected. Figure 4 shows this graph, and the diagonals show the amounts of combined alkalis ($Na_2O + K_2O$).

There are three distinct fields of distribution of granites. The granites having $(Na_2O + K_2O) < 9$ occupy the field situated entirely below the radius

TABLE 3

Some Molecular Ratios of West African Granites (numeration that of table 1)

No.	SiO_2	$\frac{K_2O}{Na_2O}$	K_2O+Na_2O	$\frac{K_2O+Na_2O}{CaO}$	No.	SiO_2	$\frac{K_2O}{Na_2O}$	K_2O+Na_2O	$\frac{K_2O+Na_2O}{CaO}$
1	121.0	0.77	11.0	5.24	31	110.6	0.3	9.2	1.46
2	111.5	0.67	9.7	1.8	32	113.8	0.94	7.4	1.07
3	114.1	0.47	10.4	2.0	33	120.9	1.12	9.9	4.12
4	122.5	0.77	10.9	6.4	34	123.1	1.57	10.8	5.68
5	123.6	0.79	10.4	5.46	35	121.7	1.18	9.4	3.18
6	121.1	0.58	11.4	5.0	36	117.3	0.86	11.33	3.33
7	114.3	0.38	11.3	2.57	37	122.1	1.5	9.85	4.7
8	120.5	0.20	11.9	3.97	38	117.1	0.33	12.25	2.27
9	117.6	0.34	10.0	2.75	39	122.7	0.17	12.4	6.52
10	107.4	0.19	9.5	1.04	40	116.8	0.67	12.25	6.125
11	107.9	0.36	10.25	1.53	41	126.3	0.7	8.5	3.15
12	105.1	0.15	7.7	1.01	42	112.9	0.66	9.68	1.8
13	103.3	0.41	8.0	0.87	43	127.0	0.9	9.85	5.8
14	108.5	0.48	7.4	1.14	44	119.6	0.66	11.08	2.58
15	107.1	0.48	10.4	1.6	45	118.5	0.29	11.66	3.64
16	113.2	0.63	9.48	1.72	46	122.4	0.26	11.03	2.76
17	104.8	0.25	9.7	1.21	47	118.2	0.28	8.63	1.46
18	120.0	0.58	7.1	2.03	48	119.0	0.21	11.1	3.5
19	120.1	0.94	8.35	1.9	49	118.4	0.24	9.82	2.4
20	116.0	0.99	11.35	3.54	50	117.1	0.23	11.04	2.2
21	102.3	0.5	6.14	0.56	51	109.2	0.28	7.88	1.09
22	117.8	0.5	8.55	1.64	52	124.2	1.7	6.12	1.17
23	113.4	0.56	7.2	0.99	53	117.8	1.355	10.6	3.21
24	96.0	0.38	6.2	0.5	54	107.1	1.16	11.0	2.16
25	109.1	0.29	9.42	1.3	55	115.3	1.44	11.7	3.9
26	108.0	0.36	10.34	1.54	56	120.4	1.24	11.2	4.48
27	105.1	0.41	9.6	1.01	57	124.8	0.5	9.3	5.8
28	112.0	0.45	8.4	1.31	58	120.8	0.12	12.75	31.8
29	114.8	0.13	11.0	2.2	59	118.4	0.25	9.8	6.53
30	127.0	0.5	8.75	2.37	60	121.9	0.68	13.1	4.7

indicating ($K_2O:Na_2O$) = 1. The granites richer in alkalis ($K_2O+Na_2O>9$), excepting those closely related to the first-mentioned group, are distinctly split into two subgroups, one of these being between the radii $K_2O:Na_2O$ = 0.5 and $K_2O:Na_2O$ = 2; and the other being beneath $K_2O:Na_2O$ = 0.33. The potassic subgroup includes the granites 1, 4, 5, 6, 33, 34, 35, 36, 37, 40, 43, 44, 53, 54, 55, 56, and 60; all these granites are within the late kinematic area of figure 3 excepting 34, 36, 43, 53, 54 and 55 which are not far from this field (excluding 54).

The sodic subgroup of figure 4 consists of granites 8, 29, 38, 39, 45, 46, 48, 50 and 58. Five of these granites belong to the late kinematic area (fig. 3); 29, 38, 50 and 58 are in both figures 2 and 3 far from the late kinematic fields.

Consequently, the graph of figure 4 clearly indicates that West African granites, overlapping in their petrochemistry with the late kinematic granites

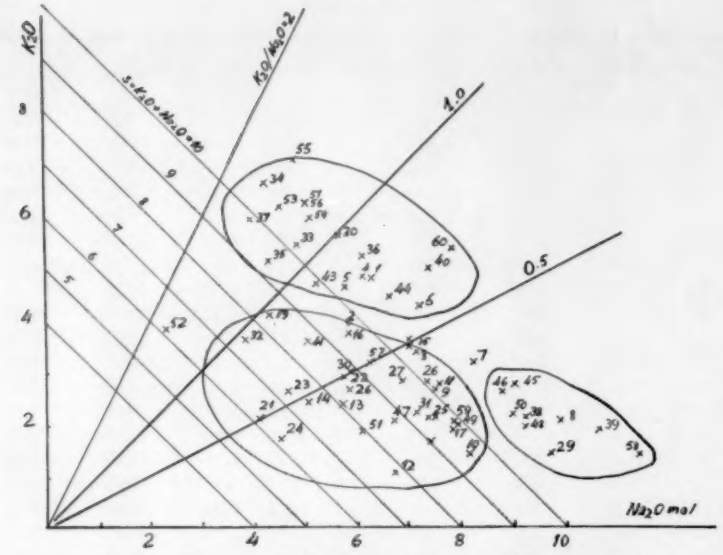


Fig. 4. The variations in alkalis of the West African granites.

of the Svecofennian orogeny in Finland, correspond to two definitely different classes, potassic and sodic.

As is to be expected, the West African granites overlapping with the synkinematic field of granites show no splitting in the graph, but their composition is rather granodioritic in regard to the alkali ratio.

The relationship of $\frac{alk}{c}$ *and fm.*—In the graph of figure 5, the ratios $\frac{alk}{c}$ and fm are compared with each other. The granites on this graph are distributed so that at values $\frac{alk}{c} = 2.5$ and $fm = 15$ there appears a strong bending of the field. There are practically no granites having simultaneously $\frac{alk}{c} > 2.5$ and $fm > 15$. The area limited by values of $\frac{alk}{c} > 3.5$ and $fm < 15$ contains the following granites: 1, 4, 5, 6, 8, 33, 34, 37, 39, 40, 43, 45, 48, 55, 56, 57, 60. All these granites occur in figure 3, either within or close to the field of the Finnish late kinematic granites.

DISCUSSION OF RESULTS OBTAINED FROM THE GRAPHS

The granites overlapping with the late kinematic field of the Svecofennide granites.—From all the graphs presented in figures 2 to 5 it can be seen that there is a definite group (roughly group 1, fig. 2) which in all graphs occupies its own field, and which overlaps with the field of Svecofennide late kinematic granites in figures 3 and 5. According to the descriptions of the authors who

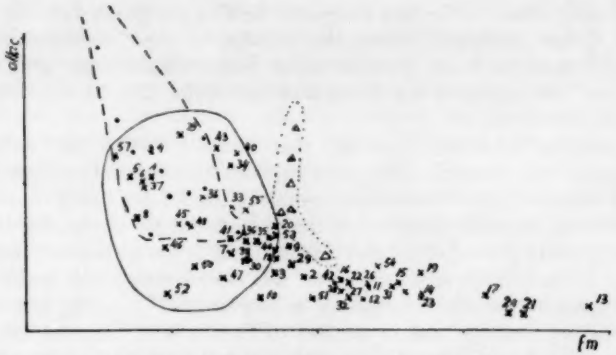


Fig. 5. The relationship of alk/c to fm. • = late kinematic granites of Finland; △ = postkinematic granites of Finland; X = West African granites; — — — — — late kinematic field of the Svecofennide granites; . . . . . postkinematic field of the Svecofennide granites; ———— the West African granites the composition of which is near that of the Finnish Svecofennide late kinematic granites.

published the corresponding analyses, the granites of this group of the Gold Coast and of the Osi area in Nigeria are in good agreement with the late kinematic granites in general. Some examples will be given:

Granites 1 to 8 are of the Gold Coast, and, according to Junner and Harwood (1928, p. 6-7), granite 1 (specimen 15500 of Junner) has intruded the schists of the Birrimian (?) system. The potash-feldspar is in excess of plagioclase, which is essentially albite. The granite contains muscovite in excess of biotite, and the cited description gives a picture typical for late kinematic granites; the authors still remark (p. 6): "the rock is free from pressure-effects."

Granite 8 is likewise, according to Junner and Harwood (1928, p. 7), a typical late kinematic granite intruding the argillaceous phyllites and sericite schists, its feldspar being essentially albite. Granites 5 and 6 are dikes in granite 4 (specimen 3197 of Junner) which, according to Junner and James (1947), is "pinkish quartz-rich biotite granite." Granite 57 is definitely a late kinematic granite; it occurs in the Kangari Hills near Makong, Sierra Leone, intruding the basic to ultrabasic schists, there associated with small sulphide mineralization. Granite 56 is from the Osi area in Nigeria; it occurs as a dike "with cross-cutting relation towards the enclosing granite" (King and de Swardt, 1949, p. 32).

In the case of granites of the French territories in West Africa, there also distinct grouping can be made, but only from the petrochemical point of view. In spite of the fact that there certain granites overlap with the late kinematic field of the Svecofennide granites in every considered respect, this group can hardly be petrologically explained if we use only the field descriptions given by the authors. Bodin (1951) divided the granites of French West Africa on the basis of their mode of occurrence. His "granites syntectoniques" belonging to the concordant batholiths are, according to him, similar to the synkinematic granites (see p. 402), but, in spite of this, they

are well represented in the late kinematic field of the graph (18, 33, 34, 37) as well. Correspondingly, among the granites of the "synkinematic petrochemistry" there are many granites which Bodin classified as "granites posttectoniques" belonging to the discordant batholiths (23, 24, 25, 26, 27, 28, 29, 30, 38, 40, 41, 42, 43).

It may be remarked, however, that Bodin (1951, p. 89) found both petrographic and chemical differences between his syntectonic (type Baoule) and post-tectonic (type Bandoukou) granites, the former being characterized by monzonitic mineral composition and potassic-sodic chemistry, the latter being in general granodioritic and akeritic, and in their chemistry tending to be sodic. In the present study, however, it is clearly shown that Bodin's petrographic grouping hardly corresponds to any definite grouping based on the petrochemistry, but that also in granites of French West Africa distinct petrographic groups occur, one of these well overlapping with the petrochemistry of Svecofennide late kinematic, the second with synkinematic granites. It may also be remarked, however, that all granites that fall within the field of late kinematic granites of the graphs need not be late kinematic, since there are varieties of synkinematic granites affected by potassium metasomatism that have, therefore, a chemical composition typical of potassic late kinematic granites. Also among the synkinematic granites there often occur portions, real intrusions of renewed magma, which in their petrochemistry correspond to the late kinematic granites, and in addition, in migmatic zones the general picture may be that of synkinematic granites, the paleosomic material actually being related to the late kinematic granite intrusions. Hence it cannot be always determined, solely from the chemical analyses or from study under the microscope, whether a certain granite is late or synkinematic. An assumption can be made, but final proof, separately obtained for each case, must be derived from accurate field observations.

One feature still may be mentioned: In figure 6 a variation diagram similar to that of figure 1 but including only the granites overlapping with the late kinematic field of Svecofennide granites is shown. Intersection of the

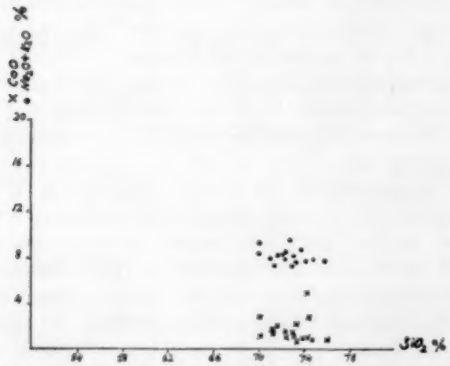


Fig. 6. Variation diagram showing the West African granites overlapping in their petrochemistry the Svecofennide late kinematic granites.

alkalic and calcic curves is not seen, but it seems most likely that the alkali-lime index can hardly be more than 57, probably somewhat less. Hence in this respect also, the West African granites of late kinematic field do not agree with the general trend of other granites shown in figure 1. It may be remembered also that neither will the youngest late kinematic granites of Precambrian orogenies elsewhere fit in the differentiation series of other igneous rocks. They always remain outside.

The granites of group 2 in figure 1.—These granites tend to be granodioritic (p. 406) in composition. According to descriptions by the authors who have published the corresponding analyses, they tend to be gneissose. Furthermore, the group 2 granites of the Gold Coast and the Osi area of Nigeria are concordant with the schistosity and strike of the adjacent schists. Among the granites of West Africa petrochemically belonging to this group, the following ones, according to statements of Bodin (1951), belong to the discordant batholiths: 22 to 30, 38, 41, and 42. Some of them are "porphyritic," containing large insets of microcline, plagioclase, and/or quartz, a feature not uncommon in the synkinematic granites of Precambrian orogenies in general. Typical granites of this kind are 2 and 3, both from Gold Coast (Junner, 1940, p. 37). The occurrence of microcline as insets in these granites indicates that they are porphyroblasts rather than phenocrysts, as is also the case in most similar granites of Svecofennide orogeny.

In figure 7 the al-si graph is reproduced, but only that part of it which does contain the granites of the synkinematic field. There is also shown the "differentiation curve" of Simonen (1948), drawn for Svecofennide synkinematic rocks. A hypothetical differentiation curve is also drawn for the West African granites, which correspond in their petrochemistry to the synkinematic granites. The distribution of the latter granites in the direction of this curve only indicates the variations in amount of assimilated (or granitized) basic material. So are to be understood those granites (10, 13, 17, 21, 24, 51) whose composition differs from that of the majority of the granites of this

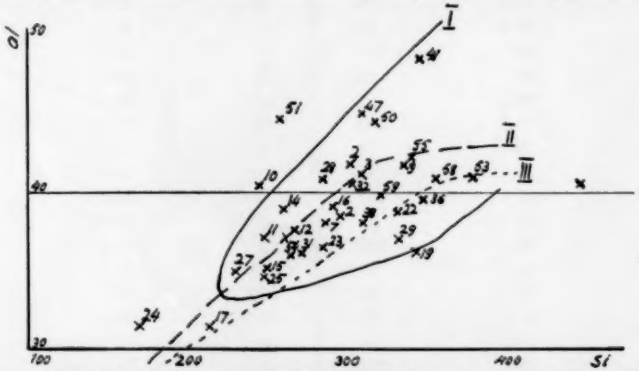


Fig. 7. The West African granites of the chemical composition of the Svecofennide synkinematic granites and granodiorites. I = the field of the mentioned West African rocks; II = the "differentiation curve" of the West African (Birrimian) granites; III = the corresponding curve of the Svecofennide synkinematic granites after Simonen (1948).

group. One of them (21) has also been described by Bodin (1951, p. 40) as being granitized amphibolite (24 is quartz diorite). Numbers 13 and 17 are hornblende-bearing granodiorites. If one compares the distribution of the granites of figure 7 with the curve of Simonen, the West African granites seem in general to be richer in alumina than the Svecofennide synkinematic granites.

Granite 52 is interesting. From the graphs it can be seen that this granite is extremely rich in quartz (figs. 2 and 3), the ratio alk/c being remarkably low (fig. 2) in spite of that, and that its alkali content is low and predominantly potassic (fig. 4). In figure 3 it falls within the late kinematic field. According to Obermuller (1941, p. 67), a mylonitized biotite gneiss is in question. Consequently, the biotite gneiss has acquired additional potassium

TABLE 4

The Number of Cations in the Standard Cell of Some West African Precambrian Granites and the Corresponding qz Values of Niggli. Arranged by increasing volume (numeration that of table 1)

No.	Number of cations in the standard cell	qz	No.	Number of cations in the standard cell	qz
13	98.2	37	36	94.7	116
17	98.2	38	44*	94.5	129
24	98.1	28	8	94.5	132
27	97.6	42	59	94.4	118
15	97.5	44	53	94.4	130
54	97.0	52	9	94.3	123
26	96.9	55	48*	94.3	131
11	96.8	57	23	94.2	109
21	96.7	52	56*	94.2	143
25	96.7	60	6*	94.0	145
10	96.5	51	39*	94.0	133
38	96.0	81	1*	93.8	150
7	95.9	89	32	93.8	123
31	95.8	80	46*	93.8	147
58	95.7	104	49	93.8	140
12	95.7	85	22	93.6	138
20	95.5	91	47	93.4	137
55	95.5	102	19	93.3	146
2	95.4	93	4*	93.2	165
3	95.4	94	33*	93.2	162
29	95.4	110	34*	93.2	168
51	95.3	86	57*	93.05	182
40*	95.2	100	35*	93.0	167
42	95.2	94	5*	92.8	191
16	95.1	94	37*	92.7	180
14	95.0	91	43*	92.5	222
60*	95.0	120	30	91.5	224
45*	94.8	122	41	91.4	233
50	94.8	104	18	91.0	194
28	94.7	100	52*	90.6	251

* The granite fits in the field of late kinematic granites shown in figure 3.

and quartz during the shearing. The comparatively high lime content (in comparison with alkalis, fig. 2) may be due to epidote, the presence of which in a mylonite is most probable.

The numbers of cations of the standard cell of rocks.—Barth (1952, p. 82) has remarked that in most rocks oxygen makes up about 94 percent by volume, and silica and metals make up less than 6 percent by volume. Hence, if we want to compare isovolumetric rock units, we should compare units containing the same number of oxygens. According to Barth, the leptologic structure of most igneous rocks is such that for 160 oxygens there are always nearly 100 cations. A volume of this size is called by Barth "the standard cell of a rock." If one calculates the number of cations in the standard cell, variations in these values will consequently show the variations in the volumes of the rocks.

In table 4 is listed the number of cations of a standard cell of the West African granites considered in this paper. They vary between 90.6 and 98.2, and the interesting feature in this variation is that the granites overlapping with the late kinematic field in figure 3 are all characterized by a comparatively large volume, that is, by a small number of cations, less than 95.0. The majority of the granites corresponding in their petrochemistry to the Svecofennide synkinematic granites have the number of cations > 95.0; 12 of them > 96.0, and among them there are "granitized amphibolite" of Bodin (p. 412), most granodiorites and hornblende-granites. All muscovite-bearing granites have cations less than 95.0 in number.

In figure 8 the qz-values of Niggli are plotted on a diagram (ordinate) against the numbers of cations (abscissae). The volume grows nearly linearly;

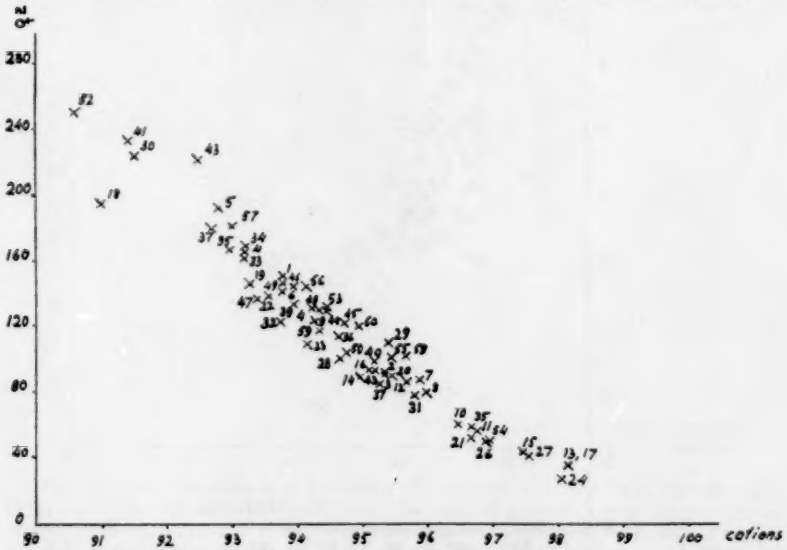


Fig. 8. The relationship between qz-value of Niggli and the number of cations in the standard cell of rocks of Barth.

consequently, the volume increases in semilinear proportion to the increasing amounts of the quartz, a feature in good agreement with the findings from the petrographical graph (fig. 3); and alumina also increases in the same direction. Figure 9 shows that volume increases together with al as well, but the linear proportion is not as clear as in the case of qz.

The Svecofennide synkinematic granites, which include gneisses concordant to the schistosity of preserved or enclosed schists (the gneissosity being a characteristic feature for this kind of granite), approach in their composition granodiorites, and similar granites in general have been explained by several authors to be the products of granitization. The late kinematic granites, on the contrary, show clear evidence in favor of their origin by intrusion.

The study of the numbers of cations of Barth's standard cell of rocks (table 4) shows definitely that the granites occupying the "synkinematic field" on the graphs of this paper have less volume than those of the "late kinematic field." That is, the granites that originated by metasomatic processes have less volume than the granites probably of igneous origin.

On the accessory constituents of the granites.—Apatite and sphene are the standard accessories always mentioned in petrographic descriptions of granites. Both these minerals contain lime, but in chemical analyses they appear in the form of TiO_2 and P_2O_5.

In calculation of the normative minerals the apatite is regularly considered but sphene is usually neglected, TiO_2 being calculated into ilmenite

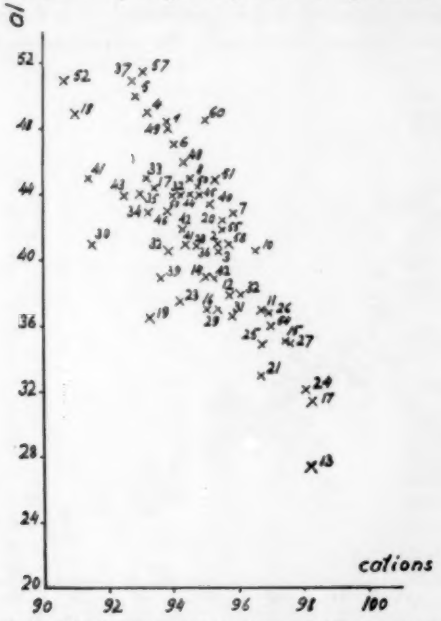


Fig. 9. The relationship between the al-values of Niggli and the number of cations in the standard cell of rocks of Barth.

($FeO \cdot TiO_2$). The sphene, however, is a characteristic accessory constituent of most granites, and especially of the synkinematic ones.

Distribution of both mentioned minerals in different granites seems at first glance to be occasional, but taking them together they distinctly follow in their amount the femic constituents of the granites, as one can see from figure 10 where the sum of apatite and sphene (weight %) is plotted against fm-values. Expectedly, the granites having the highest numbers of cations in the standard cell of Barth are also richest in the mentioned accessory minerals. This finding also indicates that silica, alkalis, and alumina have been introduced mainly during the granitization and granite-forming processes, the femic constituents together with accessory sphene and apatite being derived from the pre-existing materials, either granitized or assimilated.

The analyses of granites from the Gold Coast and Nigeria taken in the present study give the contents of barium and strontium. The BaO content is especially interesting. All granites in which barium was determined contain 0.08 to 0.16 percent, except soda granite from the Gold Coast (8), which contains only traces of BaO, and gneissic granodiorite (13) with 0.01 percent BaO.

The contents of strontium, on the contrary, are rather low.

Unfortunately, the analyses showing the content of BaO are too few to allow any discussion, and in addition they are all from either the Gold Coast

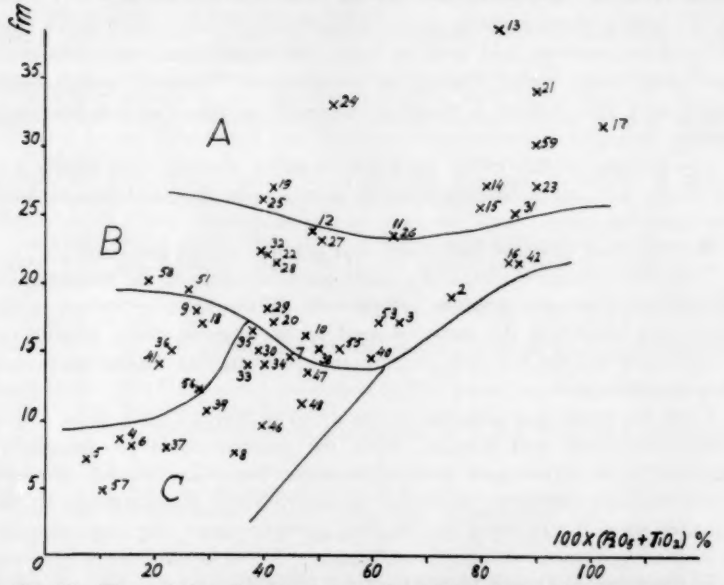


Fig. 10. The variations in the contents of combined P_2O_5 and TiO_2, related to the variations of the fm-value of Niggli. A = the field of granites having the number of cations in the standard cell of Barth (n) more than 96.5; B = granites with $95 < n < 96.5$; C = granites with $n < 95$ (in general West African granites overlapping the late kinematic fields).

or the Osi area of Nigeria. Such barium contents, however, are not regular in granites. For instance, the granites of Gwanda Gold Belt in Southern Rhodesia, according to analyses published by Tyndale-Biscoe (1940, p. 44-45), contain as a rule traces or nil of barium (except one dike forming "aplogranite" with 0.09 percent BaO).

CONCLUSIONS

Owing to their chemical composition, the Birrimian granites of West Africa can be divided into two definite groups:

(1) Those of usually granodioritic composition or approaching it, which occupy a definitely limited field in all graphs of figures 2 to 5. Their composition is characterized by $\frac{alk}{c} < 3$; fm is variable in most cases, however, between the values of 15 and 30; $6 < alk < 11$, sodium usually being in excess of potassium ($1 > K_2O:Na_2O$); SiO_2 is very variable; the number of cations in the Barth standard cell is usually more than 95.0. On the average these granites seem to be somewhat richer in alumina than the Svecofennide granites of the corresponding petrochemistry.

(2) A definite group of granites exactly overlapping in their petrochemistry the late kinematic field of the Svecofennide granites of Finland (fig. 3) where these granites occur discordantly cutting other rocks (also synkinematic granites) and tend to form dikes and veins, and often occur migmatizing older rocks. Owing to granitization, however, synkinematic granites may also acquire a chemical composition typical of late kinematic granites.

The granites of this group are richer in silica, alumina, and alkalis than those of the first group, and the number of cations in the Barth standard cell is less than 95.0.

Among these granites both sodic and potassic subgroups occur.

These two groups correspond in their petrochemistry to the Svecofennide syn- and late kinematic granites respectively. In the field, according to the authors who published the analyses used in the present study, granites of the Gold Coast and the Osi area, Nigeria are in agreement with the two groups in this respect as well.

From the experience obtained by the writer in Sierra Leone, there, within the Sula Mountains and Kangari Hills, the granites could be dependably determined to be either syn- or late kinematic. Necessary analytic material was not available, however, but from the micrometric measurements on the integration stage it was found that in their petrochemistry they also are probably in good agreement with the Svecofennide syn- and late kinematic granites.

The granites of French West Africa fall into the mentioned petrochemical groups, but these groups do not fit into the classification used in French West Africa, which is based on the concordant and discordant nature of the batholiths.

References

Backlund, H. G., 1936, Der "Magmaaufstieg" in Faltengebirgen: Comm. géol. Finlande Bull. 115, p. 293-347.

————, 1946, The granitization problem: Geol. Mag., v. 83, p. 105-117.

Barth, T. F. W., 1952, Theoretical petrology: New York and London.

Bodin, L., 1951, Contribution a l'étude des granites Birrimiens dans le Précambrien de l'Afrique Occidentale Française: French West Africa, Direction des Mines Bull. 12.

Bolgarsky, Michel, 1950, Étude géologique et description pétrographique du Sud-Ouest de la Côte d'Ivoire: French West Africa, Direction des Mines Bull. 9.

Dixey, Frank, 1925, The geology of Sierra Leone: Geol. Soc. London Quart. Jour., v. 81, p. 195-222.

Dixey, Frank, and Willbourn, E. S., 1951, The geology of the British African colonies: 18th Internat. Geol. Cong., Great Britain, Rept., pt. 14, p. 87-109.

Eskola, Pentti, 1932, On the origin of granitic magmas: Min. pet. Mitt., v. 52, p. 455-481.

Goloubinow, R., 1938, Relations des terrains métamorphiques redresses et des granites dans la région Guineo Soudanaise: French West Africa, Direction des Mines Bull. 1.

Hirst, T., 1942, The geology of the Konongo gold belt and surrounding country: Gold Coast Geol. Survey Bull. 14.

Junner, N. R., 1930, Geology and mineral resources of Sierra Leone: Mining Mag., v. 42, p. 73-82.

————, 1935, Gold in the Gold Coast: Gold Coast Geol. Survey Mem. 4.

————, 1940, Geology of the Gold Coast and western Togoland with revised geological map: Gold Coast Geol. Survey Bull. 11.

Junner, N. R., and Harwood, H. F., 1928, Microscopical features and chemical analyses of certain representative igneous rocks from the Gold Coast, British West Africa: Gold Coast Geol. Survey Bull. 4.

Junner, N. R., and James, W. T., 1947, Chemical analyses of Gold Coast rocks, ores and minerals: Gold Coast Geol. Survey Bull. 15.

King, B. C., and Swardt, A. M. J. de, 1949, The geology of the Osi area, Ilorin province: Nigeria Geol. Survey Bull. 20.

Kitson, A. E., 1928, Provisional geological map of the Gold Coast and western Togoland with brief descriptive notes thereon: Gold Coast Geol. Survey Bull. 2.

Marmo, Vladi, 1954, The geology of an elliptical drainage system, north of Bumbuna, Sierra Leone: Presented to the III Director's Conference of Geological Surveys of West Africa.

Marvier, L., 1953, Notice explicative de la carte géologique d'ensemble de l'Afrique Occidentale Française: French West Africa, Direction des Mines Bull. 16.

Obermuller, A., 1941, Description pétrographique et étude géologique de la région forestière de la Guinée Française: French West Africa, Direction des Mines Bull. 5.

Perrin, René, and Roubault, M., 1949, On the granite problem: Jour. Geology, v. 57, p. 357-379.

————, and ————, 1950, Metamorphism of the Trias in the Alps: Geol. Mag., v. 87, p. 89-101.

Pollett, J. D., 1951, The geology and mineral resources of Sierra Leone: Colonial Geology and Min. Res., v. 2, p. 3-28.

Read, H. H., 1948, Granites and granites, *in* Gilluly, James, chairman, Origin of granite: Geol. Soc. America Mem. 28, p. 1-19.

————, 1952, Metamorphism and granitization: Geol. Soc. South Africa Trans., v. 54, annexure.

Reynolds, D. L., 1947, The granite controversy: Geol. Mag., v. 84, p. 209-223.

Simonen, Ahti, 1948, On the petrochemistry of the infracrustal rocks in the Svecofennidic territory of Southwestern Finland: Comm. géol. Finlande Bull. 141.

Tyndale-Biscoe, R. I., 1940, The geology of the country around Gwanda: Southern Rhodesia Geol. Survey Bull. 36.

Wahl, W., 1936a, Om granitgrupperna och bergskedjeveckiningarna i Sverige och Finland: Geol. fören. Stockholm Förh., Band 58, Heft 1, p. 90-101.

————, 1936b, The granites of the Finnish part of the Svecofennian Archaean mountain chain: Comm. géol. Finlande Bull. 115, p. 489-505.

Geological Survey Department
Freetown, Sierra Leone

[American Journal of Science, Vol. 253, July 1955, Pp. 418-424]

AGE OF THE OBSIDIAN FLOW AT GLASS MOUNTAIN, SISKIYOU COUNTY, CALIFORNIA

CHARLES W. CHESTERMAN

ABSTRACT. Samples of wood from tree trunks standing in a bed of pumice at Glass Mountain, eastern Siskiyou County, California, give a maximum age of 1660±300 years, a minimum of 1107±380 years, and an average of 1360±240 years, when dated by the radiocarbon method.

As the trees were killed by the pumice fall, the age of the pumice is no more than 1660±300 years and no less than 1107±380 years. The age of the rhyolite obsidian and composite flows that overlie the pumice cannot exceed 1660±300 years, and are more probably only 750 to 1000 years.

INTRODUCTION

Glass Mountain, a prominent peak of volcanic glass, stands high on the Medicine Lake Highland in eastern Siskiyou County, a few miles west of the Modoc-Siskiyou county line. The Medicine Lake Highland, which culminates at Mount Hoffman at an elevation of 7913 feet, is bordered on three sides by a plateau of lavas that has an average elevation of 4800 feet.

Glass Mountain was briefly described by Powers (1932, p. 280), and by Peacock (1931, p. 271), who also described other geologic features in the Modoc Lava Bed quadrangle. The first detailed account of the mountain was by Anderson (1933), who reconstructed its geologic history and discussed the relations of the various glassy rocks. A more comprehensive report on the Medicine Lake Highland was later published by Anderson (1941) in which the volcanoes of the area and the formation of Glass Mountain were discussed thoroughly.

During an investigation of the pumice deposits in the vicinity of Glass Mountain for the California State Division of Mines, the presence of standing tree trunks was called to the writer's attention in 1951 by Roy N. Fouch, owner of the pumice property. The trunks were examined and photographed in the field, their position with respect to the pumice beds noted, and samples of the wood collected for further study. Upon the suggestion of Professor Howel Williams, of the Department of Geology at the University of California, samples of the wood were sent to Dr. W. F. Libby at the Institute of Nuclear Studies in Chicago, where the age of the wood was determined by the radiocarbon method. The writer is indebted to Professor Howel Williams for aid in obtaining radiocarbon dating of the wood samples, to Dr. W. F. Libby for making the age determinations, to Drs. R. A. Cockrell and B. A. Anderson, of the Department of Forestry at the University of California, for identifying the wood samples used, and to Dr. G. Dallas Hanna, California Academy of Sciences, for valuable assistance and suggestions made during the course of this investigation.

GEOLOGY OF GLASS MOUNTAIN

Glass Mountain stands well above many of the other peaks on the northeast part of the rampart which encircles Medicine Lake and is particularly prominent when viewed from the north and northeast. In direct contrast to the surrounding forest-covered ridges and peaks, Glass Mountain is quite

barren of vegetation. It has an elevation of 7622 feet and rises at least 650 feet above its foundation of older lavas.

Glass Mountain is made up for the most part of silicic glassy rocks which form several flows and domes that overlie breached pumice cones and older flows of basalt, dacite, and spherulitic obsidian (fig. 1). Upon this latter

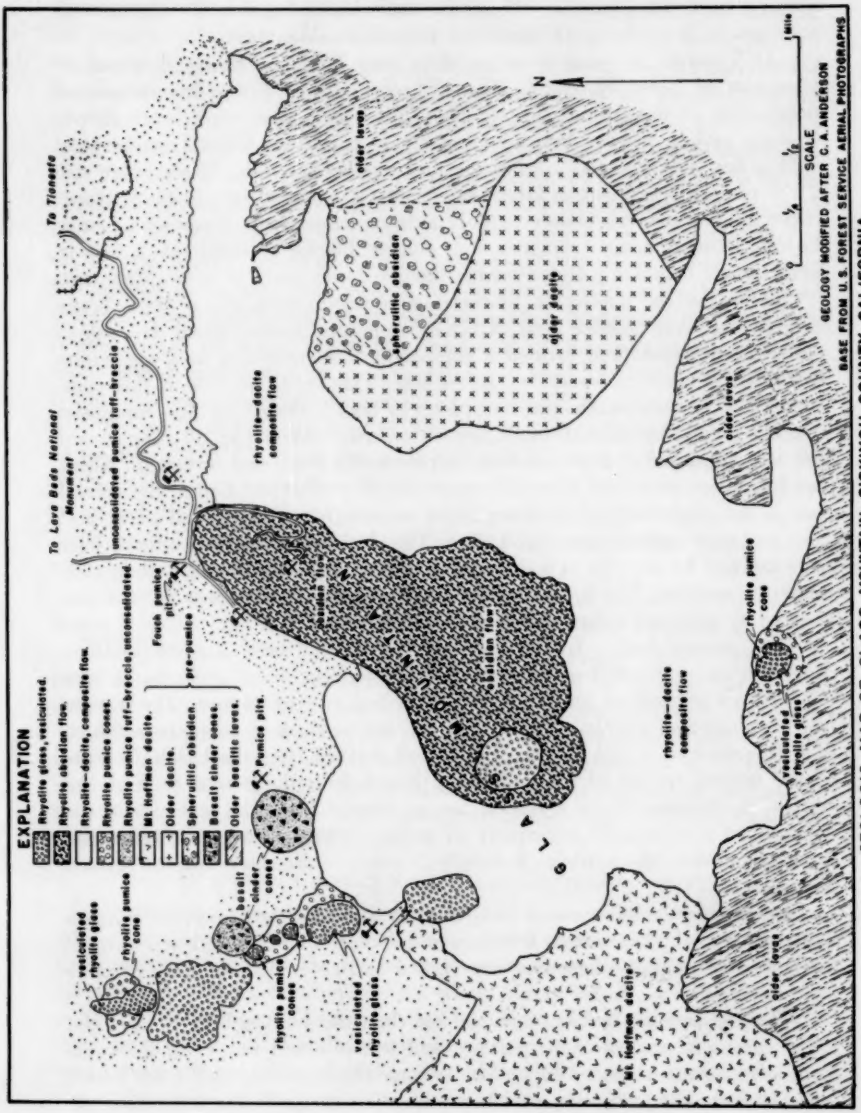


Fig. 1

series of older flows several vents developed along a fissure that strikes approximately N30°W. From these vents an abundance of grayish-white pumice was discharged to form at least seven cones, of which the largest was probably located near the present site of Glass Mountain. The pumice from the vents was widely distributed over the surrounding country and formed a loosely consolidated pumice tuff-breccia covering a fan-shaped area that extends out in a northeasterly direction from Glass Mountain.

At Tionesta, a small town on the Great Northern Railroad, about 10 miles east of Glass Mountain, the tuff-breccia forms a thin mantle several inches deep on the ground. Nearer Glass Mountain, however, it forms deeper deposits, and in a small area about one-half mile from Glass Mountain test drilling has indicated the tuff-breccia to a depth of 60 feet. The average size of the pumice fragments is larger near Glass Mountain than in those places where the tuff-breccia mantle is only a few inches thick. Numerous bombs showing "bread crust" surfaces and pumice blocks as much as 2 feet in diameter are commonly found on the pumice cones north of Glass Mountain.

Following the deposition of the pumice tuff-breccia, glassy lavas broke through the large pumice cone at Glass Mountain, poured down the eastern and western slopes, and formed a composite flow composed of stony dacite and rhyolite obsidian some 3½ miles long. The upper surface of this composite flow is very rough and hazardous to travel. Overlying this composite flow is a second rhyolite obsidian flow of less areal extent (fig. 1). The second flow was emplaced as a viscous lava that formed a flow front or margin which stands out conspicuously from the composite flow. The obsidian in the second flow is variously colored, ranging from massive black to banded black and gray and even mottled brown and black. The closing stages of volcanic activity were marked by the rise of a dome of medium-gray rhyolite glass containing numerous vesicles. The upper surface of this dome is pumiceous in part and covered by collapsed spines and partly filled depressions.

The pumice beds.—In the open pits in the tuff-breccia north of Glass Mountain are exposed two separate beds of pumice which indicate at least two distinct periods of volcanic activity giving rise to pumice. The bottom bed rests upon an uneven surface of basalt, red to black in color, from which it is separated by a thin veneer of dark soil derived from the basalt. Because of the uneven nature of the underlying basalt flow, the bottom pumice bed ranges in thickness from a few inches to several feet. The material in the bottom bed is composed principally of angular pumice fragments that range in size from dust-like particles to bombs 6 inches in diameter, and are stained dirty gray.

Separating the two pumice beds is a pumiceous, dirty brown soil horizon that ranges in thickness from 6 inches to a foot or more. In this soil horizon the trees were rooted when they were killed and entombed by the second or top pumice fall.

The top pumice bed is much thicker than the bottom bed. It has been well exposed in a number of quarries and test pits and ranges in thickness from a few feet to at least 30 feet. The average thickness exposed in the Fouch pit is 12 feet. The pumice fragments are angular, range in size from dust-like

particles to bombs 6 inches in diameter, and are grayish-white in color. Minor amounts of black obsidian and small angular fragments of pinkish rhyolite and dark-brown basalt are also present in the top bed.

The rhyolite obsidian flow (second obsidian flow) along the northwest margin of Glass Mountain overlaps the underlying composite (stony dacite-rhyolite) flow and rests directly upon the top bed of the pumice tuff-breccia. All contacts between these several rock units are sharp, and it is not possible to determine the intervals of quiet and erosion between the tuff-breccia and the overlying flows of volcanic glass. In all probability the interval was one of quiet since the pumice cones are fairly well preserved, and the loosely consolidated pumice tuff-breccia can have offered little resistance to erosion.

The buried tree trunks.—During the course of mining pumice at the Fouch pit, several buried tree trunks were exposed. The largest of these trunks is 8 feet tall, 24 inches in diameter at the butt, and 14 inches in diameter at the top (pl. 1-A). The smallest trunk measures 7 feet tall and about 6 inches in diameter at the top where the tree was broken off. All the trunks examined are exceedingly well preserved, strongly resembling fence posts that have been in the ground for a few years. The wood in the trunks was found to be perfectly sound, and several of them contained so much pitch that all tools used to obtain samples soon became heavily encrusted with a sticky coating of pitch.

The surface of the trunk of the largest tree is fluted parallel to the length of the tree (pl. 1-A). Since the trunk is fluted all over, it is thought that the fluting was due to forest fires that consumed much of the tree, especially the sap wood. Had the flutings appeared only on one side of the trunk, the fluting could possibly have been caused by the abrasive action of the pumice fragments as they hurled through the air.

A small amount of bark was found at the base of one of the trunks, but it was so water-logged and decayed that no samples were obtained for study.

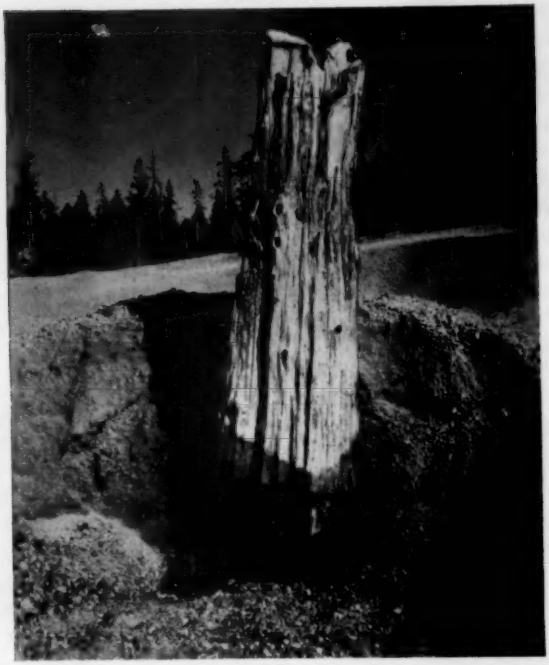
All the trunks were standing in a vertical or nearly vertical position and, prior to mining operations, were completely covered by pumice. The tops of the trees could not be found nor were any found during the course of mining.

The trunks are rooted in the soil horizon and the pumice bed lying beneath. Samples of their woods were submitted to Professors R. A. Cockrell and B. A. Anderson, who identified them as *Pinus ponderosa*, one of the several species of hard pines which now grow in the vicinity of Glass Mountain and on the Medicine Lake Highland.

AGE OF THE LAST PUMICE FALL AND RHYOLITE-OBSIDIAN FLOW

In attempting to assign a tentative age in years to either the last pumice fall or the second rhyolite-obsidian flow, certain assumptions were made. The first assumption is that the largest tree, which measures about 24 inches in diameter, was at least 225 years old when it was killed and completely engulfed by the pumice. The age of this tree was determined by counting the rings of growth. This establishes an interval of time between the pumice falls as on the probable order of 300 to 350 years. The second assumption is that the outpourings of the composite flow and the rhyolite-obsidian flow were

PLATE 1



A

B

part of a single cycle of volcanism and followed in very close succession the deposition of the top bed of the pumice tuff-breccia.

The age in years given by the radiocarbon method is 1660±300 years as a maximum, 1107±380 years as a minimum, and 1360±240 years as an average, and this actually establishes a tentative age for the last pumice eruption. Since the interval of time between the last pumice eruption and the outpourings of the flows of rhyolite obsidian is not known, the tentative age in years of the latter flows is not known.

In describing the Burnt Lava Flow, which is located only a few miles south of Glass Mountain, Finch (1933, p. 181) assigns a tentative age of the flow at 3000 years: " . . . Nearly mature trees are growing on the cinder cone (also called the High Hole Crater) as well as at places in the flow itself. Some trees that were growing on the flow next to the youngest flow were estimated to be 300 years old. Pumice fragments and occasionally small pieces of dark-gray obsidian are found on all flows, though they become less abundant toward the southern end of the area."

Undoubtedly, the pumice lying upon the Burnt Lava Flow came from Glass Mountain. The last pumice fall at Glass Mountain is approximately 1360±240 years old, and since some of this pumice lies upon Burnt Lava Flow, the Burnt Lava Flow is older than the pumice.

It is possible to determine the age of the Burnt Lava Flow by the radiocarbon method since, according to Finch (1933, p. 181), " . . . Both charred and uncharred tree remains are found at many places along the edges of the flow." By determining the age of the Burnt Lava Flow, it would then be possible to determine the interval of time between it and the overlying pumice, and also arrive at some fairly definite conclusions regarding the various intervals of time between successive volcanic eruptions.

CONCLUSIONS

As the age of the wood according to the radiocarbon method is 1360± 240 years, and assuming that the interval of time between the last pumice eruption and the outpouring of the composite and rhyolite flows was at least 350 years, the age of the Glass Mountain rhyolite obsidian flow would be 1000±300 years. If, however, the age of the last pumice eruption is the minimum, 1107±380 years, and the interval of time between the eruptions was 350 years, the minimum age of the Glass Mountain rhyolite-obsidian flow would be approximately 755± years. This age determination is slightly greater than that given by Peacock (1931, p. 271) whose estimate of 500 years was

← A. Close-up of the largest tree trunk found in the Fouch pumice pit. All wood exposed in this trunk is heart wood, which is full of pitch and has an odor typical of present-day living hard pines. The wood has been identified as *Pinus ponderosa*. Roots of the trunk are in the soil horizon and pumice bed below. Dark coloration on lower part of trunk is due to moisture. Observer faces north.

← B. North tip of Glass Mountain is in the background. Fouch pumice pit is in the foreground. Pumice bed (P) is about 12 feet thick and represents the second or latest pumiceous eruption. It is overlain by the flow of rhyolite-obsidian (ro), about 200 feet in thickness, the front of which may be seen in the middle distance. Observer faces southeast.

based in part upon legends of the Modoc Indians and upon the presence of a dead cedar tree which is estimated to have been standing for 500 years.

References

Anderson, C. A. 1933, Volcanic history of Glass Mountain, northern California: Am. Jour. Sci., 5th ser., v. 26, p. 485-506.

———, 1941, Volcanos of the Medicine Lake highland, California: Calif. Univ., Dept. Geol. Sci., Bull., v. 25, p. 347-422.

Finch, R. H., 1933, Burnt lava flow in northern California: Zeitschr. Vulkanologie, v. 15, p. 180-183.

Peacock, M. A., 1931, The Modoc lava field, northern California: Geog. Rev., v. 21, p. 259-275.

Powers, H. A., 1932, The lavas of the Modoc Lava Bed quadrangle, California: Am. Mineralogist, v. 17, p. 253-294.

California State Division of Mines
San Francisco, California

REVIEWS

Introduction to Theoretical Mechanics; by R. A. BECKER. P. xiii, 420; 246 figs. New York, 1954 (McGraw-Hill Book Company, $8.00).—The ideal textbook is one that is satisfactory to both students and teachers. *Introduction to Theoretical Mechanics*, which is a text designed for physics majors, appears to satisfy that requirement. The author has carefully prepared a text with many illustrative problems and many well-chosen exercises for the student to attempt. Many of the problems have been chosen from the Cambridge treatises by Lamb, Routh, Ramsey, and Love. In addition the application to problems of modern physics is stressed.

Beginning with a chapter on vector analysis, the author proceeds to cover the statics and dynamics of particles and of rigid bodies. The central force problem, statistics of a suspended cable, accelerated frames of reference, top motion, vibrations and normal coordinates, and the La Grangian and Hamiltonian formulations are among the topics that are treated. An appendix containing a review of ordinary differential equations and Fourier series is present for convenience to the student.

The chapter on generalized coordinates is an excellent example of the care that has been taken by the author. He shows how one can use the equations of La Grange to find forces of constraint. It is also pointed out that L is not always equal to T-V and that the Hamiltonian is not always the total energy.

The reviewer can recommend this text without any reservation.

PHILIP ROSEN

Low Temperature Physics; by C. F. SQUIRE. P. x, 244; illustrated. New York, 1953 (McGraw-Hill Book Company, $6.50).—In these days of rapidly increasing research activities, a book which surveys a given field of endeavor is generally a welcome addition to the literature. *Low Temperature Physics* by C. F. Squire is a survey of the properties of matter at low temperatures. Beginning with a discussion of the methods of obtaining low temperatures, the author proceeds to cover the properties of liquid helium, superconductors, magnetic materials, dielectric materials, and the thermal characteristics of the solid state. This wide range of subject matter consumes about 240 pages.

Along with discussions of experimental behavior of matter at low temperatures, the author injects chapters and paragraphs on the theoretical aspects of the subject. In a chapter on the equation of state, the method of finding the second virial coefficient of quantum gases using the concept of the "Slater Sum" is described. A poor description is given of the free volume theory of the liquid state and no mention is made of the Yvon, Born, Green, and Kirkwood theory of liquids. In this chapter the author is not careful to distinguish between statistical quantities for γ and for μ space.

In chapter 6, the author describes the theory of liquid helium of F. London in a superficial manner. The gaps in the logical development are marked. Also given in this chapter are short sections on the two-fluid model with an application to the "second sound" problem. In describing Tisza's theory of "second sound," the peculiar statement is made that "he emphasized the complete lack of rigidity of liquid helium. . . . " The theory of He II of

Landau is disposed of in about a page and the incorrect statement is made that "Rotons go over into phonons as the λ point is approached."

On the whole this reviewer finds that the book is brief and superficial. In many sections the logical development is discontinuous. The ordering of material is sometimes annoying because comprehension of a section depends on material further on in the book. The author relies heavily on references to the literature to overcome some of these difficulties but with little success. The one aspect of the book that can be praised is the author's ability to stress the unsolved problems in low temperature physics. This ability often proves stimulating. PHILIP ROSEN

Seismology; by K. E. BULLEN. P. viii, 132; 15 figs. London, 1954 (Methuen & Co.) and New York (John Wiley & Sons, $2.00).—This small volume, easily carried in a coat pocket, gives a reasonably up-to-date and concise outline of a difficult and rapidly growing scientific discipline. The treatment is elementary for users who have fair equipment in mathematical physics. Equations that are fundamental in seismic theory are derived sketchily, and readers who may desire fuller mathematical background are referred to the author's larger textbook. Anyone who will take the mathematical derivations on faith can still follow with profit the clear English text.

In the words of the author, a well-known theoretical seismologist in the University of Sydney, the general plan of the book is "to trace the course of seismology, in broad outline, from the stage of field observations through instrumental seismology and the related theory of transmission of seismic waves, to the point at which a significant contribution is made to knowledge of the Earth's deep interior and related matters." An explanation of longitudinal and transverse waves in an ideally homogeneous medium is followed by discussion of problems involved in fitting the theoretic concepts to our inhomogeneous Earth. The longest chapter, "Seismology and Geology," explains the use of seismic methods in exploring the structure of the Earth's crust. Large uncertainties and rapid changes in pictures drawn from these studies are emphasized when we realize that Bullen's book was written just too early to permit mention of the large-scale investigation in this country by Tatel, Adams, and Tuve.

Birch's contributions in the study of deeper zones are mentioned favorably. Laymen find especially fascinating the probing of the deep interior, and are impressed by the essential agreement among leading students on several major points, including an abrupt rise in density together with a change from solid to fluid phase at depth about 2900 km, and the existence of an inner core with considerable rigidity. On other points opinions are still far apart. Does the depth 2900 km mark an abrupt change in chemical composition? Bullen favors the view that the inner core is composed of metals, but seems open minded to a suggestion that ultramafic rock makes up the fluid part of the core—"region E"—as well as the lower part of the mantle. Lay readers will be puzzled by this. Can a critical pressure be invoked to explain both an abrupt increase in density and a transition from solid to fluid state?

The author's discussions are well documented, and each chapter ends with a selected bibliography. Let us hope for future editions of this helpful little book, to keep us posted on advances in one of the most active fields of physical science. CHESTER R. LONGWELL

Geology of the Valyermo Quadrangle and Vicinity, California; by LEVI F. NOBLE. U. S. Geological Survey Geologic Quadrangle Map No. 50. Washington, 1954 (2 sheets, $1.00).—The Valyermo geologic map is the second of this Survey series for California. The first, the Pearland Quadrangle (G. Q., No. 24), was also by Noble and was reviewed in this JOURNAL (1954, v. 252, p. 509). Here, as in the Pearland Quadrangle, the mapped area straddles the San Andreas fault on the north side of the San Gabriel Mountains, some 40 miles northeast of Los Angeles. On the Valyermo six-minute map sheet, which also includes small portions of two adjoining quadrangles, are three cross sections, two black-line perspective figures (by Philip King), and an explanation of rock units. The text sheet includes a fault map of southern California, a geomorphic-tectonic map of the quadrangle, and a geologic map of a 50-mile stretch of the San Andreas zone, which includes portions of both the Pearland and Valyermo quadrangles.

This work, which has involved a considerable portion of Noble's efforts during a span of more than forty years, is a meritorious achievement in geologic research and clarity of presentation. It serves to re-emphasize the importance of the geologic map to interpretations of Earth history; in this case a "biography" of the San Andreas fault zone is developed. It also serves as a model of geologic presentation; in this case a segment of the San Andreas is "laid out" to provide maximum understanding by others. Only two cartographic errors are known to this reviewer: (1) the color of the upper Martinez on the sections is not in accord with the map; and (2) a sliver of Punchbowl formation instead of Pelona schist is shown south of Cajon Creek, in the southeast corner of figure 3.

Noble describes the San Andreas *fault* as trending N. 65° W. across the quadrangle and, as clearly marked by a chain of recently developed narrow ridges and trenches, mostly in alluvium. This fault trace is within a like trending, relatively depressed, San Andreas *fault zone*, ranging from one-half to one mile in width, which comprises brecciated Holcomb quartz monzonite (new name, Cretaceous?) and Pinyon Ridge granodiorite and gneiss (new name, Jurassic?) overlain by up to a few hundred feet of highly folded and faulted continental clastic, western facies, Punchbowl formation (upper Miocene). The Punchbowl is unconformably overlain by a thin folded and faulted section of the Harold formation (Pleistocene). Both of these formations occur in separate facies on either side of the San Andreas fault. The next younger Shoemaker gravel (new name, Pleistocene) is locally highly deformed and occurs only north of the San Andreas fault in this quadrangle, although the unit does occur south of the fault in the quadrangle to the west. Older and Younger alluvium, locally deformed into ridges and trenches, commonly occur within the San Andreas fault zone.

North of the fault zone a ridge of only slightly fractured Holcomb quartz monzonite, including northwest-trending pendants of Paleozoic (?) limestone, is blanketed northward by the northward-thickening alluvial deposits of Antelope Valley. South of the fault zone is a highly faulted and folded two-mile wide synclinal block comprising 4000± feet of eastern facies Punchbowl formation and 6000± feet of marine clastic Martinez formation (Paleocene) which rest on the Pinyon Ridge granodiorite and gneiss. This block is separated to the south from Pleasant View Ridge, comprising the Pleasant View complex (new name, Mesozoic to Precambrian) of plutonic and metamorphic rocks, by a 1000-foot wide zone of similar crushed basement rocks, which occur between the steep N. 65° W. trending Punchbowl and San Jacinto faults.

In this reviewer's opinion Noble's work here will become recognized as a classic in the study of the character, amount and history of fault displacements as well as a fundamental contribution to the understanding of the San Andreas fault zone. His conclusions regarding movements on the fault may be summarized as follows: (1) recency of movements is attested by the development of ridges, trenches, and scarps in alluvium; (2) stream channels have been offset in a right lateral sense a distance in excess of one mile; (3) the separation of occurrences and facies of the Shoemaker gravel and Harold formation indicates a right lateral-slip on the San Andreas of approximately five miles since Pleistocene time; (4) a unique match of facies within the Punchbowl formation substantiates a cumulative right lateral-slip of 30 miles since upper Miocene time; (5) a mismatch of basement rocks on either side of the San Andreas zone in this area and the possibility of matching crystalline rocks in the San Bernardino Mountains with the Pleasant View complex suggest the possibility of over 50 miles of displacement in the same sense.

Although Noble expressed some of these concepts with respect to large cumulative strike-slip on the San Andreas as early as 1926, he met with what turns out to be arbitrary opposition, and refrained until lately from reaffirming his conclusions. In the Pearland report, with the evidence restricted to that quadrangle, he demonstrated only a few miles of strike-slip displacement, whereas in this report, with a 50-mile segment of the fault considered, he demonstrates a few tens of miles of right lateral movement. It seems likely to this reviewer that, when a still longer segment of the fault zone is as intelligently mapped and older rocks are matched, still greater strike-slip displacements will be ascertained. It will be enlightening to know where the counterpart of the Vasquez formation of the Palmdale Quadrangle occurs, if preserved, on the north side of the San Andreas, or the Mill Creek beds of the Redlands Quadrangle on the south side of the fault; and what regional mapping and petrographic studies of the Pelona schist, and other pre-Tertiary crystalline rocks, may reveal about the history of movements on this great fault zone.

MASON L. HILL

The Principles of Historical Geology; by J. WILLIS STOVALL and HOWARD E. BROWN. P. viii, 472; New York, 1954 (Ginn and Company, $6.00).—This highly readable new text of historical geology maintains a uniform pace

with no appreciable variations in writing style or degree of technicality. The book is greatly enhanced by the vivid paleomorphologic maps prepared for each geologic period and the 12 physiographic-structural block diagrams of the United States. These excellent additions to the text produced by Edwin Raisz should be very helpful in providing the student with a grasp of the broader aspects of each period and the relationships of structure, geologic history, and physiography of areas in the United States. The stratigraphic columns and cross-sectional diagrams by Edward Schmitz are well executed and are effective in illustrating geologic history and principles. The reconstructions of prehistoric life (17 pls.) by Thomas W. Voter were based on exhibits of the American Museum of Natural History and are successfully employed in providing the student with an over-all glimpse of the faunas and floras of ancient times. Carefully selected and well-reproduced photographs are liberally used throughout the text to illustrate stratigraphic, structural, and lithologic features. Plates of illustrations of representative fossils are presented for most of the periods of the Paleozoic and Mesozoic except for the curious lack of any illustrations of representative fossils for the Mississippian, Pennsylvanian, and Permian periods. This omission is difficult to understand in view of the importance of such fossil groups as the brachiopods, crinoids, blastoids, ammonoids, and fusulinids in correlating the rocks and interpreting the history of these periods.

The early chapters of the book are logically devoted to developing a concept of the scope and principles of historical geology. This is well developed through lucid discussions of such topics as place of the Earth in the universe, origin of the universe, development of the geologic time scale and means of determining absolute age, nature and evolution of life, fossils and their significance, and principles of correlation.

The following chapter on the biology of the major taxonomic groups of animal and plant life, in conjunction with the appendix for the identification and classification of fossils, should serve to familiarize the student with the important aspects of each group so that subsequent descriptions of the fossil record for each period are more meaningful to the student. This is a welcome change from many historical texts, since it has been the reviewer's experience that many first-year geology students have had no taxonomic biology and therefore have little or no knowledge of the fundamentals of classification and what it means. This chapter however could readily be improved by the inclusion of illustrations of the morphology of living and fossil forms of the more important groups. This is particularly true since some of the important fossil groups such as the foraminifers and graptolites are poorly illustrated (or are absent) in the plates of fossils for the various periods. Although not of fundamental importance in teaching historical geology, the order of treatment of the invertebrate phyla is not consistent with current thought. Although the correct taxonomic position of the graptolites is still somewhat doubtful, it is quite generally agreed that they are not members of the phylum Coelenterata. Generally modern paleontology texts treat the echinoderms after the arthropods and as the last major invertebrate phylum since in many respects the echinoderms are more closely related to the vertebrates. The

authors in Appendix B, p. 462, state: "Arachnids . . . may possess great evolutionary significance, as it is regarded by many authorities as a link between the lower forms and the vertebrates." This statement may be entirely correct, but in the interests of objectivity and coverage the authors should have discussed the evidence (equally convincing, or more so) which suggests the echinoderms as the most closely related to the vertebrates.

The succeeding chapters devoted to discussing the physical history of each geologic period are well organized and presented. The chapter usually opens with a short discussion of the existing physiography of North America. This is followed by a general description of rocks formed during the period, the major subdivisions of the period, the physical history based on an interpretation of the rocks and fossils found in the system, the distribution of the system in foreign areas, the economic products derived from rocks of the system, climate, and life.

Although every book will have occasional errors due to type-setting mistakes and oversights in proof reading, there appear in this book mistakes that are difficult to attribute to these sources. Some of these mistakes are as follows: the map showing the distribution of Late Proterozoic mountains is labeled as Late Paleozoic; a photograph of a St. Peter sandstone and Platteville limestone section is captioned " . . . St. Peter sandstone and older Platteville limestone . . . "; a figure of *Columnaria* is called *Streptelasma*; the block diagram of Niagara Falls creates the impression that at the present falls a shale stratigraphically higher than the Lockport dolomite is holding up the falls; the text has the dip of normal faults of the Triassic of Connecticut and New Jersey interchanged; the authors state that south of the Connecticut area the Triassic sandstone and shales are chiefly greenish-gray, whereas they really are predominantly red in New Jersey, Pennsylvania, Maryland, and Virginia; the Jurassic *Rhynchonella* is called a pelecypod; and a photograph of Tertiary sediments folded into a gentle syncline is captioned as an anticline.

Although the student of historical geology may receive erroneous impressions on several points from this book in its present form, the new paleomorphological maps and physiographic-structural block diagrams make the book very attractive as a text for historical geology. Upon casual examination the reviewer was impressed by the usability of this text, but closer examination raised serious doubts. It is hoped that an early revision of the book with slight changes in content and correction of the many errors will be forthcoming. This book should then become a highly valuable addition to the historical geology texts now available. ELROY P. LEHMANN

Journal of the Geological Society of Australia. Volume 1 for the year 1953. Adelaide, South Australia, June 1954. P. 133; 34 figs., 6 pls.—Australian geology has made great strides since World War II but has lacked a mouthpiece through which its results could be made known to the outside world. Except for a few articles that occasionally appeared in American and English periodicals, the large geological literature on Australia was hidden

away in the proceedings of half a dozen Royal Societies, four or five museum reports series, and similar publications of equal inaccessibility to the average geologist abroad. The newly established Geological Society of Australia has now published its first volume of scientific papers with M. F. Glaessner as editor. Although it contains, strangely enough, no general announcement or policy statement, the reviewer has been informed that it will be the policy of the new Journal to give high priority to papers of general interest, which will appeal to geologists in other continents, and present a cross section of geological thinking in Australia.

The five papers contained in this first volume are representative of this aim. They are:

Scapolitization in the Cloncurry district of northwestern Queensland; by A. B. Edwards and G. Baker

Mesozoic stratigraphy and history of the Canning Desert and Fitzroy Valley, Western Australia; by R. O. Brunnschweiler

Stereographic distinction of linear and planar structures from apparent lineations in random exposure planes; by E. Den Tex

The Rheid concept in geotectonics; by S. W. Carey

Turbidity currents and the graptolite facies in Victoria; by E. S. Hills and D. T. Thomas

If succeeding volumes measure up to the standard of this debutant, the new Journal will soon gain recognition and increased circulation, and the voice of Australian geology will become more audible abroad.

CURT TEICHERT

Publications Recently Received

U. S. Geological Survey Professional Papers: 260-B, C, D, Bikini and Nearby Atolls, Part 2, Oceanography (physical); by W. S. von Arx, W. H. Munk, M. C. Sargent, and M. K. Robinson ($ .75). 260-E, F, G, Bikini and Nearby Atolls, Part 2, Oceanography (biologic); by M. C. Sargent, T. S. Austin, M. W. Johnson, and G. A. Cooper ($ .60). 260-H, Recent Foraminifera of the Marshall Islands, Part 2, Oceanography (biologic); by J. A. Cushman, Ruth Todd, and R. J. Post ($1.75). 260-J, K, L, Bikini and Nearby Atolls, Part 3, Geophysics; by M. B. Dobrin, Beauregard Perkins, Jr., R. W. Raitt, L. R. Alldredge, Fred Keller, Jr., and W. J. Dichtel. 260-Q, Marine Annelids from the Northern Marshall Islands; by Olga Hartman ($ .25). 266, Late Paleozoic Stratigraphy of Central Cochise County, Arizona; by James Gilluly, J. R. Cooper, and J. S. Williams ($ .45). Washington, 1954.

Les Fondements Logiques des Mathématiques, 2d ed.; by E. W. Beth. Paris, 1955 (Gauthier-Villars, 2500 francs, paper cover).

Axiomatique Intuitionniste sans Négation de la Géométrie Projective; by Mlle. N. Dequoy. Paris, 1955 (Gauthier-Villars, 1250 francs, paper cover).

The Geology of the Koedoesrand Area, Northern Transvaal (an explanation of sheets 35 and 36 (Koedoesrand)); by H. N. Visser. Union of South Africa Geological Survey, Department of Mines. Pretoria, 1953 (10 *s*, including map).

The Northern Natal Coal-field (Utrecht-Newcastle Area). Part 1, Geological; by J. J. G. Blignaut and F. J. J. Furter. Part 2, Chemical and Physical; by W. H. D. Savage. Union of South Africa Geological Survey Coal Survey Memoir 2. Pretoria, 1952 (30 *s*, including map).

Iron in Virginia; by E. O. Gooch. Virginia Division of Geology Mineral Resources Circular 1. Charlottesville, 1954.

Colorado Mining Laws. Colorado Bureau of Mines Bulletin 16. Denver, 1954.

Anthropology; by J. M. White. New York, 1955 (Philosophical Library, $2.75).

Harker's Petrology for Students, 8th ed. revised; by C. E. Tilley, S. R. Nockolds, M. Black. New York, 1955 (Cambridge University Press, $3.50).

Bau und Entstehung der Alpen, 2d revised ed.; by Leopold Kober. Wien, 1955 (Franz Deuticke, DM 36.-).

The Geology of the Norton Oil Field, Norton County, Kansas; by D. F. Merriam and E. D. Goebel. Kansas Geological Survey Bulletin 109, Part 9. Lawrence, 1954.

Summary of Water Flood Operations in Illinois Oil Pools During 1953; by P. A. Witherspoon, E. G. Jackson, et al. Illinois Geological Survey Circular 193. Urbana, 1954.

National Advisory Committee on Research in the Geological Sciences, Fourth Annual Report. Geological Survey of Canada. Ottawa, 1954 ($ .50).

Electricity and Magnetism; by R. P. Winch. New York, 1955 (Prentice-Hall, Inc., $7.75).

The Bedrock Geology of the Ellington Quadrangle (with map); by G. E. Collins. Connecticut Geological and Natural History Survey Quadrangle Report 4. Hartford, 1954.

Applied X-rays, 4th ed.; by G. L. Clark. New York, 1955 (McGraw-Hill Book Company, $12.50).

Harvard University Peabody Museum of American Archaeology and Ethnology Papers, Vol. 42, No. 1, Reports of the Ramah Project No. 5: Land-use in the Ramah Area of New Mexico; by J. L. Landgraf ($1.65). Vol. 49, No. 2, The Monagrillo Culture of Panama; by G. R. Willey and C. R. McGimsey ($4.65). Cambridge, 1954.

Summary of Geology and Ground-water Resources of the Eastern Shore Peninsula, Virginia; by Allen Sinnott and G. C. Tibbitts, Jr. Virginia Division of Geology Mineral Resources Circular 2. Charlottesville, 1954.

Stratigraphic Nomenclature in Reports of the U. S. Geological Survey; by Geologic Names Committee. Washington, 1953.

Isotope Geology; by Kalervo Rankama. New York, 1955 (McGraw-Hill Book Company, $12.00).

An Introduction to Plant Taxonomy; by G. H. M. Lawrence. New York, 1955 (Macmillan Company, $3.25).

Introducing Sea Shells; by R. T. Abbott. New York, 1955 (D. Van Nostrand Company, $2.50).

The Romanian Oil Industry; by C. N. Jordan. New York, 1955 (New York University Press, $10.00).

Laboratory Explorations in General Zoology, 3d ed.; by K. A. Stiles. New York, 1955 (Macmillan Company, $3.75).

U. S. Geological Survey Water-supply Papers: 1223, Water Levels and Artesian Pressures in Observation Wells in the United States in 1952, Pt. 3, North-Central States ($1.00). 1224, Pt. 4, South-Central States ($ .65). 1226, Pt. 6, Southwestern States and Territory of Hawaii ($1.00). 1238, Surface Water Supply of the United States, 1952, Pt. 5, Hudson Bay and Upper Mississippi River Basins ($1.75). 1247, Pt. 13, Snake River Basin ($1.50). 1258, Ground-water Resources of the Middle Loup Division of the Lower Platt River Basin, Nebraska; by D. W. Brown and F. H. Rainwater ($1.00). 1262, Chemical Characteristics of Delaware River Water, Trenton, New Jersey, to Marcus Hook, Pennsylvania; by C. N. Durfor and W. B. Leighton ($ .70). 1294, Ground-water Conditions in Southwestern Langlade County, Wisconsin; by A. H. Harder and W. J. Drescher ($ .40). 1296, Geology and Ground Water Resources of the Baton Rouge Area, Louisiana; by R. R. Meyer and A. N. Turcan, Jr. ($1.00). Washington, 1954 and 1955.

U. S. Geological Survey Bulletins: 1012, C, D, Fluorspar Deposits in Western Kentucky, Pt. 2; by R. D. Trace ($ .70). 1012, E, F, Pt. 3; by W. R. Thurson, G. C. Hardin, Jr., and H. J. Klepser. 1013, Index of Generic Names of Fossil Plants, 1820-1950; by H. N. Andrews, Jr. ($ .65). Washington, 1954 and 1955.

U. S. Geological Survey Professional Papers: 260-M, N, O, P, Bikini and Nearby Atolls, Pt. 4, Paleontology; by J. H. Johnson, R. M. Todd, Rita Post, W. S. Cole, and J. W. Wells ($2.50). 272-A, The Effect of Salinity on Evaporation; by G. E. Harbeck, Jr. ($ .15). Washington, 1954 and 1955.

Evolution of the Vertebrates; by E. H. Colbert. New York, 1955 (John Wiley & Sons, $8.95).

Kansas Geological Survey Bulletin 109, Part 10: Chemical, Petrographic, and Ceramic Properties of Four Clays from the Dakota Formation in Kansas; by Norman Plummer, Ada Swineford, R. T. Runnels, and J. A. Schleicher. Lawrence, 1954.

VOL. 253 No. 7, 1955

American Journal of Science

JULY 1955

CONTENTS

GEOMORPHIC DEVELOPMENT IN HUMID AND ARID REGIONS: A SYNTHESIS
Chauncey D. Holmes 377

THE PETROCHEMISTRY OF SOME PRECAMBRIAN GRANITES OF WEST AFRICA, AND A PETROCHEMICAL COMPARISON WITH THE SVECOFENNIDE GRANITES OF FINLAND ..... *Vladi Marmo* 391

AGE OF THE OBSIDIAN FLOW AT GLASS MOUNTAIN, SISKIYOU COUNTY, CALIFORNIA ..... *Charles W. Chesterman* 418

REVIEWS

Introduction to Theoretical Mechanics; by R. A. BECKER ..... *Philip Rosen* 425

Low Temperature Physics; by C. F. SQUIRE ..... *Philip Rosen* 425

Seismology; by K. E. BULLEN ..... *Chester R. Longwell* 426

Geology of the Valyermo Quadrangle and Vicinity, California; by LEVI F. NOBLE
Mason L. Hill 427

The Principles of Historical Geology; by J. WILLIS STOVALL and HOWARD E. BROWN
Elroy P. Lehmann 428

Journal of the Geological Society of Australia. Volume 1 for the year 1953.
Curt Teichert 430

PUBLICATIONS RECENTLY RECEIVED 431